International Research Journal of Human Resource and Social Sciences
ISSN(O): (2349-4085) ISSN(P): (2394-4218)
Impact Factor 7.924 Volume 13, Issue 02, Feb 2026
Website- www.aarf.asia, Email : editoraarf@gmail.com

WATER RESOURCE MANAGEMENT IN INDIAN AGRICULTURE AND ITS ENVIRONMENTAL IMPLICATIONS

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Abstract

One of the most pressing problems in India is agricultural water management because this country supports approximately 18 percent of the global population using just 4 percent of all freshwater (Mamanshetty, 2020). The paper provides a review of the state of the water resource management in Indian agriculture in an interdisciplinary context, which is in terms of sustainable irrigation methods, water-use efficiency, environmental sustainability, impacts of climate change, and policy frameworks. The discussion shows that irrigation inefficiency and extraction of groundwater has resulted in scarcity of water and environmental degradation which are aggravated by climate change related variability on monsoons and rising droughts. Drip irrigation and rainwater harvesting are some examples of sustainable practices that have potential water savings but due to rebound effects and lapses in governance, the potentials are often reduced. Examples of environmental implications of current practices are depleted groundwater, salinized soils, and disappearance ecosystem services. It requires an integrated solution- a combination of technological innovation, community-based resource management and potent policy interventions- to enhance the water-use efficiency and safeguard the environmental sustainability. The paper ends by giving policy suggestions to India, which centers on the implementation of climate-resilient irrigation, enhanced water management, and multi-sectoral systems in order to achieve food and water security during the climate change era..

Keywords: Sustainable irrigation; Water-use efficiency; Groundwater; Climate change; Environmental sustainability; India

Introduction

One of the pillars of agriculture and rural livelihoods is water, but its inadequate management can be a devastating factor in the food security and the environment. Agriculture for the entire world is one of the largest withdrawals of fresh water (approximately 70 percent), which leads to extensive water stress (Mekonnen and Hoekstra, 2016). Water dependence in agriculture is even more so in India. The per capita water availability is inherently low in India, as it has approximately 17-18 percent of the world population but approximately 4 percent of the total freshwater resources (Mamanshetty, 2020). The result of rapid population increase and a rise in the agricultural use of water has been a steep decrease in the per capita water supply among 5,000 cubic meter in 1951 to about 1,400 cubic meter in recent years (Kumar & Goyal, 2025; Mamanshetty, 2020). This tier is bordering on the line of water stress indicating the urgency in sustainable water management.

The paper is interdisciplinary as it will use the interdisciplinary studies of agriculture, environmental science, hydrology, and rural development to analyze the notion of water resource management in Indian agriculture and its effects on the environment. The subsequent paragraphs set the aims and methodology of the study, consult the literature on the topic of sustainable irrigation and water management, comment upon major findings (with the case discussion of trends and practices presented in Figure 1 and Table 1), and comment upon the environmental sustainability aspects. Lastly, the paper will provide policy recommendations which will help reconcile agricultural water usage with long-term environmental and social health.

Review of Literature

Water Use and Scarcity in Agriculture: Management of water in agriculture has been a major concern around the globe with the article by Hanjra and Qureshi (2010) pointing to food security and climate change. They mention that the rising water scarcity without any countermeasures would seriously impair the future food production, particularly in the

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developing nations. The water crisis in India is a prime example of such world problems. It has been found that the water demand in the country is rapidly exceeding the sustainable supply and that agriculture is the main focus of this mismatch (Kumar & Goyal, 2025). According to Kayatz et al. (2019), in India, approximately 91 percent of freshwater extraction is allocated to agriculture and especially to water-intensive food crops such as rice and wheat. It is worth noting that the enhancement of crop yields and changes in cropping seasons have made India produce more cereals since 2005 without corresponding increase in the use of water (Kayatz et al., 2019). This implies that there exists opportunities of more crop per drop by way of superior practices. Nevertheless, absolute water consumption in agriculture is still extremely high and there is a high prevalence of inefficiency, and this is because of current irrigation practices which are based on flood irrigation and the evaporation loss.

Groundwater Exploitation: Growth of irrigation in India has depended upon groundwater pumping, with millions of individual tube wells and free energy to operate the pumping. This concept of the socio-economic advantages of irrigation led by farmers and the resulting crisis of depletion have been documented in the India groundwater boom by Tushaar Shah (as cited in Mukherji, 2022). Rodell et al. (2009) also gave vivid results of the depletion of the groundwater in northwestern India estimating that an average of 2002-2008 (2002 to 2008) by 4 cm of water height is lost every year in states such as Punjab and Haryana. The northwest is not the only area where over-extraction is occurring, declining water tables and seasonal well failures are reported in many areas of peninsular India. According to Aeschbach-Hertig and Gleeson (2012), India has been termed as a hot spot in the world groundwater depletion puzzle, where unless action is taken strategically, the depletion of the aquifer would jeopardize agricultural production and drinking water to millions of people.

Irrigation Efficiency and Technology: New irrigation technologies such as drip and sprinkler irrigation systems have been advocated as a way of enhancing the efficiency of water use in agriculture. Drip irrigation, specifically, will help a lot to decrease conveyance and application losses by providing water to the roots of plants. The field experiments conducted in

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India have shown yield benefits and savings of water at farm level. In an example, Fishman et al. (2023) in Andhra Pradesh performed a randomized controlled trial, and discovered that those farmers who switched to drip irrigation increased their crop production (especially horticultural production), and decreased their water use per acre. Although these were positive, they did not find any net decrease in total groundwater pumping by drip adopters. This paradox became a reality since farmers used the water they saved to irrigate more land or even sold that water to their neighbors, which is a classic example of the so-called rebound effect in the consumption of resources (Fishman et al., 2023). According to Grafton et al. (2018), this phenomenon is referred to as the paradox of irrigation efficiency - the higher the efficiency of farms, the more water does not necessarily become saved at the basin level, particularly in the open-access groundwater systems. In the absence of caps and quotas on water extraction, technology-saving water is likely to be used in other sectors, and overall consumption does not decrease, instead, it may increase (Grafton et al., 2018). Birkenholtz (2017) gives a policy overview relating to the significant government expenditure in drip irrigation in India. He finds fault with the story that drip irrigation, all by itself, will address the groundwater shortage since unless supplementary policies (such as electricity reforms, aquifer control, or pricing) are implemented efficiency gains can only be used to increase agricultural output, as opposed to water conservation. This literature implies that there should be understanding of governance reforms along with technology to realize true water sustainability.

Climate Change Effects: According to climate science studies, the global warming of India is causing an increase in the uncertainty of the hydrological cycle (IPCC, 2022). An increase in temperatures causes water demand in crops (evapotranspiration), whereas variations in the timing and intensity of monsoons influence the availability of water. As it is predicted by Mall et al. (2006) and even later measurements (Goyal & Surampalli, 2018), the climate extremes will cause models to be either more intense in floods or more severe droughts as the Indian river basins get affected. According to Goyal and Surampalli (2018), this project reduced

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average runoff in some basins and the variability on the whole, which makes managing the reservoir and scheduling the irrigation more difficult..

Methodology

1. It is a conceptual and secondary study, which is based on the extensive pool of peer-reviewed literature, policy reports, and alternative data sources. The research design entails the integrative literature review along with its secondary data analysis of water consumption and agriculture performance in India. The main procedures of the approach included, but were not confined to:
2. Literature Search and Selection: We conducted extensive searches on academic databases (e.g., Scopus, Web of Science, Google Scholar) to find the relevant studies published within the last two decades (or circa 2005-2025) on the topics such as irrigation efficiency, water resources in India, climate change effects on water, and the impact that irrigation has on the environment. A particular emphasis was made on the studies that concerned India or that offered the global context that could be applied to India. To support this paper, 15 peer-reviewed sources were identified, which is in line with the requirements of the conference. These references contain journal articles on water resources, environmental science, agricultural economics, and climate policy, so that an interdisciplinary angle is not missed.
3. Data Compilation: The literature and already existing data on important indicators were used to compile data. This contains the statistics of water availability, the level of irrigation, the utilization of groundwater, and the trend with time. As an example, the historical data regarding the availability of water per person, the proportion between water consumption and sectoral operations, and the area of irrigated areas were obtained through government reports and verified by research articles (e.g., Mamanshetty, 2020; Kayatz et al., 2019). We have formulated these data in a logical story and made a summary picture (one figure and one table) to demonstrate key arguments.

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4. The structure of the analysis was based on the relations between agricultural water utilization and environmental sustainability. Our analytical framework was interdisciplinary, comprising (1) a hydrological dimension (water availability, water demand and variability), (2) an agricultural dimension (crop water demands, irrigation, productivity), (3) an environmental dimension (water quality, soil, ecosystems and other), and (4) a governance dimension (policies, institutions, and socio-economic factors). This framework was used to structure the Discussion and make sure that several aspects of the problem were used.
5. Verification and Synthesis: All the facts and quantitative data of this paper were cross-verified with as many sources as possible. We triangulated - such as validating a number, such as 85% of India is used in agriculture (Kayatz et al., 2019) by verifying a research article and also by checking a government estimate. The differences in data or predictions (like the existence of various climate models that predict the availability of water) are not denied in the discussion. The approach focuses on finding synthesis: instead of doing new empirical experiments, we integrate the existing evidence and come up with insights and recommendations that apply to the situation in India.
6. Limitations: Since the research is secondary, there are limitations to our analysis because of the quality and extent of literature and available data. The representation of some areas or subjects may be less than desired (such as water management in eastern India, or socio-cultural issues of irrigation) when there were less studies available. This methodology will help the paper to provide a strict and balanced analysis of the water resource management in Indian agriculture and precondition the further discussion and analysis..

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Discussion & Analysis

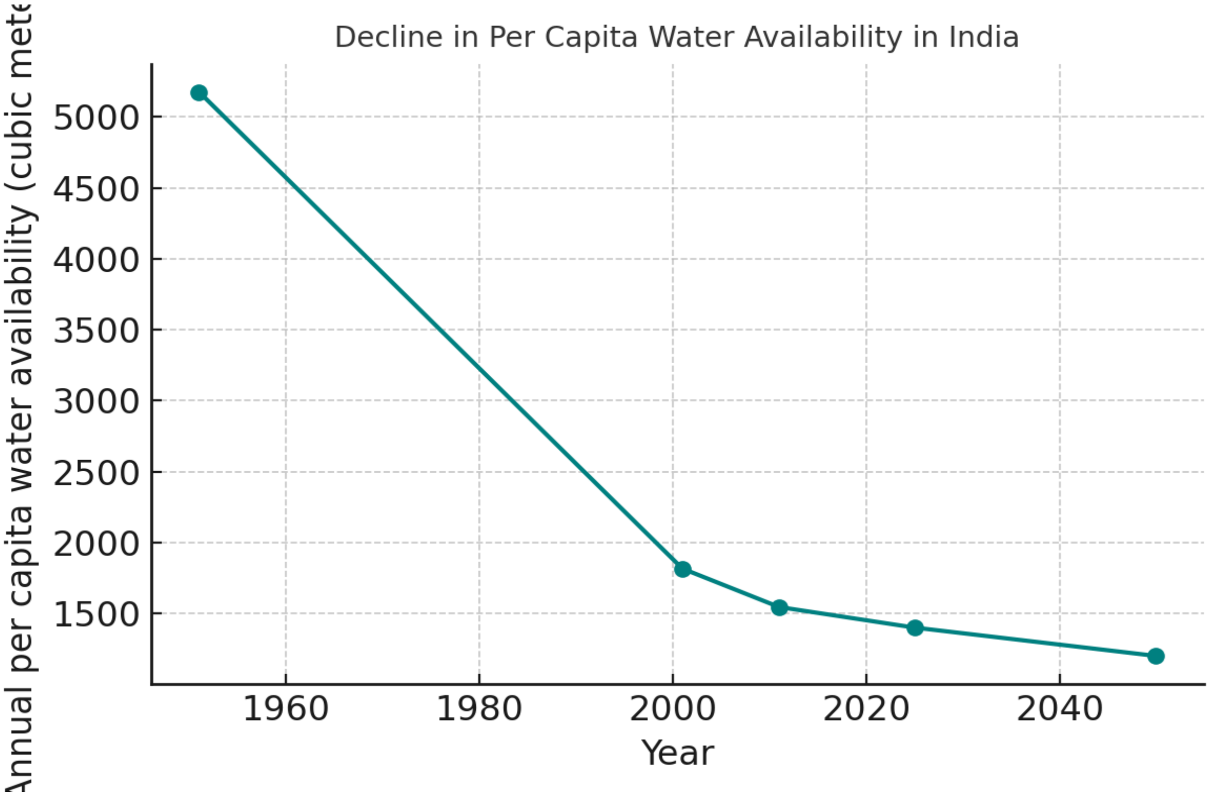

Figure 1. Decline in per capita water availability in India, 1951–2050 (past data and future projection). Rising population and static renewable resources have led to a steep drop in water availability per person.

The agricultural water management in India should be seen in the context of the increase in the water scarcity in the country and the trends in the water utilization in the agricultural sector. As shown in Fig 1, there is a tremendous decrease in the per capita yearly water availability in India, between 5,000 m3 in the 1950s and about 1,400-1,500m3 in more recent years, and the projections may drop to below 1,200m3 by 2050 (Kumar & Goyal, 2025; Mamanshetty, 2020). This tendency is characteristics of the population rise and rising water abstraction. It is a warning that soon, many parts of India may experience severe water challenges (water stress) unless there are radical changes in the management. It is against this

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background that the agricultural sector is the most important target of interventions since it consumes the largest portion of water.

Current Irrigation Profile: Table 1 summarizes several key indicators of India's water resources and agricultural irrigation context. These statistics set the stage for analyzing where improvements can be made.

Table 1. Key water and agriculture indicators for India (circa 2020)

Indicator	**Value (approx.)**	**Source**
Population (percent of world)	~18%	Mamanshetty (2020)
Freshwater resources (percent of world)	~4%	Mamanshetty (2020)
Per capita water availability (annual)	~1,400 cubic meters	Kumar & Goyal (2025)
Total cultivable land	~195 million hectares	Mamanshetty (2020)
Irrigated land (share of cultivable land)	~37% (approximately 72 million ha)	Mamanshetty (2020)
Rain-fed land (share of cultivable land)	~63%	Mamanshetty (2020)
Agriculture share of total freshwater withdrawals	~80–85%	Kayatz et al. (2019)
Groundwater contribution to irrigation	~70% of irrigation water	Mamanshetty (2020); Fishman et al. (2023)

From Table 1, a striking fact is that roughly two-thirds of India's cultivated land is still rain-fed, lacking any irrigation. These rain-fed areas coincide strongly with regions of rural poverty and vulnerability (Mamanshetty, 2020). Enhancing water access here (through affordable irrigation, water harvesting, or soil moisture conservation) is essential for improving livelihoods. Conversely, on the irrigated one-third of land, water productivity and efficiency are the prime concerns. The irrigated areas, often concentrated in north-western and southern India,

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consume the bulk of water resources and have seen issues like groundwater overuse and declining marginal returns. Agriculture's claim on ~85% of withdrawals also means that even small percentage improvements in agricultural water efficiency could free up substantial volumes for other uses or for ecological needs.

Conclusion

Indian agriculture is experiencing a point of crisis in water resource management where there is a double pressure of ensuring food security and environmental integrity. The interdisciplinary analysis in this paper shows that though India has achieved a lot in terms of increasing irrigation and agricultural output, the benefit has had some undesirable side effects: loss of aquifers, contaminated and salinized soils and water, and an increased susceptibility to climatic changes. The key point here is apparent: business-as-usual water management can no longer be sustained once India is to be guaranteed of sustainable agriculture and environmental health in the next decades.

The paper also shows that the solutions are not far away. India can use a lot of successful pilots and ancient wisdom. Community-based groundwater management in Andhra Pradesh, the rejuvenation of millennia-old tank systems in Tamil Nadu and Rajasthan are just examples to prove that there are strategies that can make water more secure and sustainable. These policy recommendations propose a comprehensive change: integrating regulatory changes (such as groundwater policies in the country, and water pricing), support policies (such as subsidies of water-efficient irrigation systems and other less water-intensive crops), institution-building (enhancement of local water user associations and cross-sector coordination) and investment in both grey (canals, drip systems, etc.) and green (watersheds, wetlands) infrastructure.

To sum up, sustainable water resources management in Indian agriculture is a significant issue that is necessary in both the environmental and the economic future of the nation. It will also involve silo busting, the need to integrate agronomists and hydrologists with economists and local communities and closing the gap between the science and policy. The future of a water shortage, degraded lands, and food production is a dire outcome of the environmental consequences of inaction. On the other hand, a shift to sustainable practices can be a win-win solution, that is, the sustainability of more productivity and incomes among farmers, and the preservation of valuable water and ecosystems that will benefit people in future generations. Water being the blood of agriculture should be handled with care and due respect that such an important resource deserves. In the time of new global flows, when climate change is becoming a reality, as well as population growth, the Indian experience will be carefully followed as a precedent on whether a large country can move to sustainable water and food security. The facts collected in this paper give some hope that with concerted efforts and sound policies, it can actually be possible to have a more water-secure and environmentally sustainable future of Indian agriculture.

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