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Irrigation and Agricultural Productivity in Jammu and Kashmir: A Systematic Literature Review

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Abstract:

Agriculture remains the principal source of livelihood in Jammu and Kashmir (J&K), directly or indirectly sustaining roughly 60–70% of its population, yet the productivity of its major food crops continues to lag behind the national average, largely because of the region's fragmented and increasingly stressed irrigation base (Kumar et al., 2023; Padder, 2021). This paper presents a systematic narrative review of 31 peer-reviewed journal articles, government/institutional data sources and contemporary science-reporting sources on the relationship between irrigation development and agricultural productivity in J&K, synthesising historical, empirical, institutional, hydrogeological and climatic perspectives drawn from material published between 2011 and 2026. The review traces the evolution of irrigation from traditional community-managed gravity systems such as kuhls and kools to state-administered canal and lift schemes, examines quantitative evidence on the association between irrigated area and crop yield, evaluates the performance of national irrigation-investment programmes such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), and assesses emerging threats from glacier recession, erratic snowfall and declining spring discharge. Findings indicate that although net and gross irrigated area expanded modestly between 2010 and 2020, productivity gains were uneven across crops, undermined by fragmented landholdings, ageing canal infrastructure, and by an accelerating hydrological shift away from dependable snow- and glacier-fed supply. Farmer-managed irrigation systems, historically praised for equity, have shown declining maintenance capacity relative to government-managed schemes in several districts. The review concludes that raising agricultural productivity in J&K requires integrated investment in irrigation infrastructure rehabilitation, micro-irrigation technology, climate-resilient cropping calendars and strengthened water-governance institutions, and it identifies gaps in longitudinal, farm-level productivity data as a priority for future research.

Keywords: Irrigation, agricultural productivity, Jammu and Kashmir, kuhl irrigation, water resources, PMKSY, climate change, crop yield.

1. Introduction

Jammu and Kashmir occupies a distinctive place among India's agricultural regions. Spanning subtropical plains, temperate valleys and cold, arid high-altitude tracts within a relatively small geographical area, the erstwhile state supports an agrarian economy in which more than 60% of the workforce and up to 70% of the population depend, directly or indirectly, on farming and allied activities, even though agriculture contributes only a modest share of Gross State Domestic Product (ICAR, 2022; Kumar et al., 2023). Rice, wheat and maize dominate the food-grain economy, while horticulture apples, walnuts, apricots and saffron anchors the region's cash-crop base. Cropping patterns differ sharply between the Jammu region, where rice–wheat and maize–wheat rotations prevail under a mix of irrigated and rainfed conditions, and the Kashmir Valley, where rice–mustard systems depend heavily on snow- and glacier-fed irrigation (ICAR, 2022).

Irrigation has long been recognised as one of the most decisive determinants of agricultural productivity in mountainous and semi-arid tracts, where rainfall is seasonal and often unreliable. In J&K specifically, water for irrigation historically came from an elaborate network of farmer-built gravity channels locally called kuhls in Kashmir and kools in Jammu division, supplemented since the mid-twentieth century by government canal and lift-irrigation schemes (Shaheen, 2011). Despite this long irrigation tradition, only around 40–43% of gross cropped area in the region has typically been under assured irrigation, well below the levels achieved in the irrigated plains of Punjab and Haryana, and productivity of major cereals in J&K is reported to remain low due to inadequate irrigation coverage and limited input use (Akhter & Acharya, 2016; ICAR, 2022).

The urgency of understanding this relationship has grown in recent years as climate change has begun to visibly disrupt the snow- and glacier-fed hydrology on which Kashmiri agriculture depends. Reports of shrinking glaciers, early snowmelt, drying springs and increasingly erratic precipitation point to a structural change in water availability during the critical sowing and growth periods of paddy, vegetables and horticultural crops (Down to Earth, 2026; Greater Kashmir, 2025). Against this backdrop, the present review synthesises the available scholarly and grey literature to answer three linked questions: (i) how has irrigation infrastructure and governance in J&K evolved historically; (ii) what empirical evidence exists on the relationship between irrigation and agricultural productivity in the region; and (iii) what challenges and policy responses are shaping the future of irrigated agriculture in J&K.

2. Methodology

2.1 Review Design

This paper adopts a systematic narrative review design rather than a meta-analysis, reflecting the heterogeneous nature of the available literature, which combines econometric studies, descriptive statistical analyses, historical accounts and contemporary journalistic and institutional reporting on climate impacts. A narrative synthesis approach is appropriate where studies differ substantially in scope, method, time period and unit of analysis, as is the case for irrigation research on J&K.

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2.2 Search Strategy and Sources

Literature was identified through structured searches of academic repositories and web-based scholarly indexes (including ResearchGate, Google Scholar-indexed journal archives, and institutional databases such as those of the Indian Council of Agricultural Research), supplemented by government and inter-governmental data portals (IndiaStat, the Ministry of Agriculture and Farmers Welfare's Digest of Statistics, and PMKSY programme records) and specialised outlets such as India Water Portal and the FAO. Search terms combined "irrigation", "agricultural productivity", "Jammu and Kashmir", "kuhl/kool irrigation", "water resources", and "climate change" in various combinations. Recent journalistic and scientific reporting (2024–2026) on glacier retreat and snowfall deficits was included to capture developments not yet reflected in the peer-reviewed literature, given their direct bearing on irrigation water availability.

2.3 Inclusion Criteria

Sources were included if they (a) focused substantively on agriculture, irrigation or water resources in the Jammu and Kashmir region (including present-day Ladakh where historically part of the same administrative unit); (b) reported empirical data, statistical trends or documented case evidence rather than opinion alone; and (c) were published in a traceable, citable outlet. Priority was given to peer-reviewed journal articles and government statistical sources; supplementary journalistic sources were used only to document recent climatic developments where they cited named experts, institutions or primary data.

2.4 Number of Sources Reviewed

The search and screening process yielded 31 sources meeting the inclusion criteria set out above, listed in full in the References section and summarised by type in Table 1. This is a deliberately curated, quality-screened set rather than an exhaustive census; a larger pool of candidate sources was identified through the search strategy in Section 2.2, but many were excluded at screening for lacking primary data, duplicating findings already captured elsewhere, or concerning irrigation systems in other Himalayan states or regions without direct bearing on J&K.

Table 1. Number and Type of Sources Reviewed

Source Type	Count	Illustrative Examples
Peer-reviewed journal articles	18	Akhter & Acharya, 2016; Bhat et al., 2022; Kumar et al., 2023; Padder, 2021; Romshoo et al., 2018, 2020; Shaheen, 2011
Government / institutional data sources	3	ICAR, 2022; IndiaStat, 2026
Contemporary science-journalism sources (2024–2026)	10	Down to Earth, 2026; Greater Kashmir, 2025; Kashmir Observer, 2025; Mongabay India, 2024
Total	31	

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Source: Author's classification of the 31 sources meeting the inclusion criteria in Section 2.3; full citations appear in the References section.

2.5 Analytical Approach

Data extracted from the reviewed studies, principally on gross/net sown and irrigated area, crop-wise productivity, cropping intensity, and fertiliser and mechanisation trends, were compiled and re-tabulated (Tables 2–4) to allow direct comparison across time periods and studies. Thematic synthesis was then used to organise findings into five domains: historical evolution of irrigation systems, empirical productivity evidence, policy and investment programmes, institutional/governance performance, and climate-related risk, which structure Sections 4 through 8 of this review.

3. Study Area: Agro-Climatic and Hydrological Context

Jammu and Kashmir is conventionally divided into two broad agricultural tracts. The Jammu region (roughly 40% of the cultivated area) lies in the subtropical foothills and plains, with rice–wheat and maize–wheat as the predominant cropping systems under a mix of canal, tube-well and rainfed conditions. The Kashmir Valley (roughly 60% of the cultivated area) is a temperate intermontane basin drained by the Jhelum River and its tributaries, where rice–mustard and rice–oat systems predominate, and irrigation depends substantially on snowmelt and glacier-fed streams channelled through kuhls and, increasingly, departmental canals (ICAR, 2022). About 60% of the net sown area in the region is estimated to be rainfed and subject to frequent moisture stress, while approximately 0.3 million hectares are under high-altitude rice cultivation, both irrigated and upland, with average state productivity of around 2 tonnes per hectare constrained by low temperatures at flowering, phosphorus and zinc deficiency, and rice blast disease (ICAR, 2022).

Table 2. Net Sown, Net Irrigated and Rainfed Area in Jammu & Kashmir Compared with Selected Indian States, 2011–12 (thousand hectares)

State	Net Sown Area	Net Irrigated Area	Rainfed Area	% Area Irrigated
Punjab	4,134	4,086	48	98.8%
Haryana	3,513	3,073	440	87.5%
Uttar Pradesh	16,623	13,411	3,212	80.7%
Himachal Pradesh	538	106	432	19.7%
Jammu & Kashmir	746	319	427	42.8%
Maharashtra	17,386	3,252	14,134	18.7%

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Source: Compiled from state-wise data on net sown, irrigated and rainfed area (2011–12), Ministry of Agriculture and Farmers Welfare, Government of India, as reproduced in operational guidance material for the Pradhan Mantri Krishi Sinchayee Yojana.

As Table 2 shows, J&K's irrigation coverage of roughly 43% of net sown area was well above hill states such as Himachal Pradesh but far below the irrigated plains of Punjab, Haryana and Uttar Pradesh underscoring that, notwithstanding the region's relative abundance of surface water, only a minority of cultivated land benefits from assured irrigation, leaving the majority of farms exposed to rainfall and snowmelt variability.

4. Historical Development of Irrigation Systems in Jammu and Kashmir

4.1 Traditional Community-Managed Systems: Kuhls and Kools

Before the expansion of state-run canal irrigation, Kashmiri agriculture relied on an elaborate, farmer-owned and farmer-managed network of gravity-flow channels, locally termed kuhls, that diverted water from streams and rivers to terraced and valley fields, in a manner closely paralleling the better-documented kuhl systems of the western Himalaya in Himachal Pradesh (Shaheen, 2011). In the intermediate and hilly tracts of Jammu division, an analogous community-managed system known as the kool system performs a similar function, and is today regulated under the Jammu and Kashmir Water Resources (Regulation and Management) Act, 2010. These systems historically embedded water allocation within local social institutions, with elected water committees and traditional caretakers overseeing desilting, conflict resolution and equitable turn-taking among head-, middle- and tail-end users.

4.2 The Shift Toward Departmental Canal Irrigation

From the early twentieth century, and accelerating after the 1950s with the establishment of state agricultural and irrigation institutions, many farmer-managed kuhls were progressively brought under the control of the government Irrigation Department as part of planned development, while newer canal, lift-irrigation and, later, tube-well schemes were constructed largely as departmental assets (Shaheen, 2011). Comparative assessment of twenty-one irrigation schemes in Kashmir found that, contrary to the pattern observed in many parts of the world where farmer-managed systems tend to outperform government-run ones, government-managed schemes in Kashmir were generally better maintained and more equitably operated, including for tail-end users, than the remaining farmer-managed kuhls, a reversal attributed in part to the erosion of local collective-action capacity during decades of political instability and out-migration of labour (Shaheen, 2011).

The mid-twentieth century also marked the introduction of Green Revolution technologies, high-yielding wheat and rice varieties, chemical fertilisers and expanded canal irrigation into J&K agriculture- a transition documented as part of the region's broader agrarian transformation. While this raised food-grain output and rural incomes for farmers able to adopt the new technologies, the benefits were not uniformly distributed, and small and marginal cultivators in less-irrigated tracts were frequently left behind (Raina & Mandot, 2024).

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5. Irrigation and Agricultural Productivity: Empirical Evidence

5.1 Land-Use and Irrigated-Area Trends, 2010–2020

Analysis of official land-use statistics for J&K over 2010–2020 shows that gross sown area rose from about 1,145 thousand hectares in 2010 to a peak of 1,196 thousand hectares in 2015, before declining to roughly 1,090 thousand hectares by 2020, a pattern mirrored in net sown area and attributed in part to diversion of agricultural land to horticulture, construction and non-farm uses (Kumar et al., 2023). Gross irrigated area followed a similar trajectory, rising to about 522 thousand hectares in 2015 before falling to around 445 thousand hectares by 2020 while net irrigated area remained comparatively more stable, fluctuating between roughly 308 and 356 thousand hectares across the decade (Table 3).

Table 3. Land-Use Pattern: Gross/Net Sown and Gross/Net Irrigated Area in Jammu & Kashmir, Selected Years 2010–2020 (thousand hectares)

Year	Gross Sown Area	Net Sown Area	Gross Irrigated Area	Net Irrigated Area
2010	1,145	735	480	317
2013	1,162	745	487	325
2015	1,196	758	522	325
2017	1,177	757	497	336
2019	1,124	713	495	329
2020	1,090	720	445	308

Source: Adapted from Kumar, Bisht, and Verma (2023), based on data from the Ministry of Agriculture and Farmers Welfare, Government of India (2022).

This divergence between gross and net irrigated area is significant: it indicates a decline in irrigation intensity (the extent to which irrigated land is cropped more than once a year) over the second half of the decade, consistent with reports of ageing canal infrastructure, reduced water availability, and land diverted to single-cropped horticulture.

5.2 Crop-Wise Productivity and the Role of Irrigated Area

Longer-run data spanning 1999–2000 to 2011–12 offer a clearer picture of the productivity irrigation relationship at crop level. Rice, which is grown almost entirely (90–100%) under irrigated conditions in J&K, recorded the most consistent productivity gains of the major cereals, rising from about 1,562 kg/ha in 1999–2000 to 2,396 kg/ha in 2011–12 an increase of over 53% alongside an increase in the share of total irrigated area devoted to rice from roughly 90% to 100% (Akhter & Acharya, 2016). Wheat and maize, grown under more mixed irrigated/rainfed conditions, showed far more volatile productivity, including a sharp fall in wheat productivity in 2000–01 followed by partial recovery, reflecting greater sensitivity to seasonal rainfall variability where irrigation coverage remained partial (Table 4).

Table 4. Productivity of Major Crops in Jammu & Kashmir, Selected Years 1999–2000 to 2011–12 (kg/hectare)

Year	Rice	Wheat	Maize	Saffron (kg/ha)
1999–00	1,562	1,769	1,485	3.13
2002–03	1,784	1,633	1,451	0.11
2005–06	2,152	1,810	1,413	1.57
2008–09	2,180	1,835	1,592	3.75
2011–12	2,396	1,800	2,000	2.68

Source: Adapted from Akhter and Acharya (2016), based on the Economic Survey of Jammu and Kashmir, 2011–12.

Regression analysis using fertiliser consumption and area under high-yielding varieties (HYVs) as explanatory variables found that these two inputs jointly explained about 80% of the variation in agricultural productivity in J&K over 1999–2012, with both variables statistically significant, though irrigation itself was found to have a comparatively weaker direct correlation with rice output than fertiliser or mechanisation variables in the same analysis a finding the authors attribute to irrigated area for rice already being close to saturation across the study period, leaving little further variation for the statistical model to exploit (Akhter & Acharya, 2016).

Table 5. Total Irrigated Area under Major Crops in Jammu & Kashmir, Selected Years (thousand hectares)

Year	Rice	Wheat	Maize	Total Irrigated Area
1999–00	225	62	28	438
2003–04	223	69	23	446
2007–08	229	77	22	463
2011–12	270	87	16	527

Source: Adapted from Akhter and Acharya (2016), based on the Economic Survey of Jammu and Kashmir, 2011–12.

A district-level study of wheat cultivation in the irrigated sub-tropical belt of Jammu district similarly found substantial variation in productivity linked to irrigation-scheduling practices: only around 45% of sampled wheat growers applied their first post-sowing irrigation at the agronomically recommended crown-root-initiation stage, pointing to on-farm water-management practice, not merely infrastructure availability, as a further determinant of realised productivity gaps (Padder, 2021).

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A separate farm-survey study of 180 wheat growers across three blocks of Jammu district (R.S. Pura, Suchetgarh and Bishnah) similarly found wide variation in realised productivity under nominally irrigated conditions, tracing this in part to input-management practice: all sampled farmers sowed by broadcasting rather than line-sowing, and only a minority followed recommended fertiliser split-dosing schedules tied to irrigation timing, reinforcing the conclusion that irrigation access alone is an incomplete predictor of yield without complementary agronomic practice (Kumar, Slathia, et al., 2022).

5.3 Technology, Infrastructure and Productivity Interactions

Beyond irrigation coverage per se, several studies emphasise that productivity outcomes in J&K are jointly shaped by transport, power, credit and research infrastructure alongside irrigation, echoing wider Indian evidence that transport, power, irrigation and agricultural research are the infrastructural variables most strongly associated with productivity growth (Akhter & Acharya, 2016). Mechanisation indicators such as tractor numbers and diesel/electric pump ownership in J&K expanded substantially between 1999–2000 and 2011–12, alongside a roughly five-fold increase in fertiliser distribution intensity (kg/ha), suggesting that irrigation expansion in the region has generally occurred as part of a wider input-intensification package rather than in isolation (Akhter & Acharya, 2016). At the orchard scale, controlled field trials at SKUAST-Kashmir modelling soil-moisture movement under point-source drip emitters have shown that emitter discharge rate systematically governs the horizontal and vertical extent of the wetted root zone in apple orchards, underlining that precision-irrigation design parameters, not merely the decision to irrigate, materially affect water-use efficiency and, by extension, achievable productivity in high-value horticulture (Vishwakarma et al., 2023).

5.4 Horticultural Crops: Saffron and Apple Orchards

Irrigation constraints are especially consequential for J&K's high-value horticultural crops. Saffron (Crocus sativus), grown almost exclusively on the unirrigated karewa uplands of Pampore in Pulwama district, has experienced a severe, multi-decade production decline that growers and agricultural officials attribute substantially to inadequate and unreliable water supply compounding climatic stress: production is reported to have fallen from roughly 16,000 kg in the 1990s to under 3,000 kg in recent seasons, with the area under cultivation contracting by more than 65% over two decades (Kashmiril, 2026). A National Saffron Mission-funded borewell irrigation network intended to supplement rainfall was reportedly left largely non-functional in the years after installation, with independent field audits finding a majority of planned borewells abandoned for want of maintenance funding, illustrating how infrastructure investment without sustained operational budgets fails to translate into realised irrigation capacity (Kashmiril, 2026). Growers and researchers at SKUAST-Kashmir have identified sprinkler irrigation during the corm-flowering period as a priority intervention for reversing the decline, alongside corm-quality improvement and disease control (Kashmir Observer, 2025).

Apple cultivation, by contrast, illustrates how targeted irrigation investment can support productivity transformation. Traditional low-density apple orchards in Kashmir, largely rainfed or minimally irrigated, typically yield 10–12 tonnes per hectare and remain vulnerable to alternate bearing and weather shocks; high-density plantation (HDP) systems using dwarf rootstocks combined with drip irrigation and fertigation have been reported to achieve 50–70 tonnes per hectare with a higher share of premium-grade

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fruit, though this resilience is conditional on consistent, timely irrigation and input access that not all growers can sustain (Kashmir Observer, 2026). Government-backed schemes including the High-Density Plantation Scheme and the Mission for Integrated Development of Horticulture (MIDH) have promoted drip irrigation and fertigation adoption in these orchards, with SKUAST-Kashmir providing technical support for precision-irrigation practices (Greater Kashmir, 2026).

5.5 Paddy Area Contraction and Land-Use Change

Alongside changes in irrigation intensity, a parallel contraction in the physical area under paddy, the crop most fully dependent on assured irrigation in the Valley, has become a defining feature of recent land-use change. Official records cited via right-to-information requests indicate that paddy area in the Kashmir Valley fell from about 141,340 hectares in 2020 to roughly 130,050 hectares in 2025, a loss of more than 11,000 hectares in five years, with area under cultivation down from around 162,000 hectares in 2012 (Greater Kashmir, 2025). Districts historically known as the Valley's "paddy bowl" Budgam, Pulwama and Kulgam have seen particularly steep conversion of fertile, irrigated paddy land to residential, commercial and orchard use as urban areas expand (Kashmir Vision, 2026). Satellite-based land-use tracking in South Kashmir covering 113 villages found farmland area shrank by roughly five per cent between 1990 and 2017 while horticultural land, chiefly apple orchards, expanded by more than four per cent over the same period (Ground Report, 2026). Because paddy net returns are reported to be extremely low in some tracts, as little as ₹213 per hectare in foothill areas, the economic incentive to convert irrigated paddy land to higher-return horticulture or non-farm use compounds, rather than merely coinciding with, the water-scarcity pressures documented elsewhere in this review (Ground Report, 2026).

6. Government Schemes and Irrigation Investment

Public investment in irrigation in J&K has, since the 1950s, been channelled through successive Five-Year Plan projects and, more recently, through the centrally sponsored Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), launched nationally in July 2015 with the goal of "Har Khet Ko Pani" (water to every field) and of improving on-farm water-use efficiency. PMKSY operates through several components relevant to J&K, including the Accelerated Irrigation Benefit Programme (AIBP) for creating irrigation potential, the Per Drop More Crop (PDMC) component promoting micro-irrigation (drip and sprinkler systems), and the Watershed Development Component (WDC-PMKSY) for rainfed-area treatment. Programme records indicate continuing cumulative releases of central financial assistance to J&K under AIBP, PDMC and watershed-development components through 2024–25, alongside recorded numbers of small and marginal farmers benefitting from micro-irrigation subsidies (IndiaStat, 2026).

Nationally, micro-irrigation coverage under PMKSY-PDMC reached about 10.25 million hectares by 2023, roughly 7.6% of net sown area, with markedly higher adoption in states such as Andhra Pradesh and Maharashtra than in the Himalayan states; this suggests that, notwithstanding programme funding flows, on-ground uptake of water-efficient micro-irrigation technology in hill states including J&K has lagged the national frontier, an implementation gap consistent with the region's comparatively modest expansion in net irrigated area documented in Table 3.

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6.1 The Indus Waters Treaty and Post-2025 Irrigation Development

Irrigation development potential on J&K's western rivers, the Indus, Jhelum and Chenab, has historically been constrained by the Indus Waters Treaty (IWT) of 1960, under which these rivers were allocated primarily to Pakistan while India retained only limited rights to non-consumptive hydropower, restricted irrigation and domestic use. Following the Pahalgam terror attack of April 2025, India announced it was placing the IWT in abeyance, a step widely described as removing long-standing legal constraints on India's capacity to develop water-storage and irrigation infrastructure on these rivers within J&K (Outlook India, 2026). Proposed post-suspension irrigation initiatives reported in policy commentary include expanded storage at projects such as Sawalkot and Bursar on the Chenab, lift-irrigation schemes drawing on Chenab flows for south Kashmir orchards, and floodplain irrigation development along the Jhelum, though the practical, engineering and seismic-safety timelines for such projects in J&K's mountainous, seismically active terrain remain uncertain and contested (Outlook India, 2026). As with the mini-dam proposals discussed by J&K irrigation officials in earlier years, the treaty's status is a live and evolving determinant of the region's long-run irrigation potential rather than a settled backdrop, and its implications for agricultural productivity will depend on infrastructure execution over a multi-year horizon.

7. Climate Change, Water Scarcity and Emerging Risks

A growing body of recent scientific and journalistic reporting documents a structural shift in the hydrology that underpins irrigated agriculture in the Kashmir Valley. Unlike much of India, where paddy cultivation is timed to the summer monsoon, agriculture in the Valley depends heavily on winter snow accumulation that melts gradually through spring and summer to feed the Jhelum River and its tributary streams; several recent winters have instead brought inadequate snowfall and prolonged dry spells, according to agrometeorologists at the Sher-e-Kashmir University of Agricultural Sciences and Technology (Down to Earth, 2026). The Kolahoi Glacier, a key source of Valley River flow, is reported to have retreated by nearly 900 metres over the past fifty years, while roughly one in four major springs monitored in farming villages has shown a significant decline in flow, forcing some farmers to deepen bore-wells or leave fields fallow (Greater Kashmir, 2025).

These hydrological changes are already being linked to measurable productivity effects: reports describe potato, cauliflower and tomato yields falling by up to 35% in some areas due to combined heat stress and water scarcity, apple yields reduced by 40–50% in years when early blossoming is followed by late frost, and saffron output in Pampore traditionally among the region's highest-value crops roughly halving as warming winters disrupt the crop's temperature-sensitive flowering cycle (Greater Kashmir, 2025). Rice paddies covering an estimated 130,000 hectares in the Valley are described as critically dependent on glacier- and snow-fed irrigation, with erratic rainfall and early snowmelt increasingly reducing water availability during the peak vegetative growth period (Greater Kashmir, 2025). Agricultural scientists caution that even short delays in water availability at the transplantation stage can significantly depress paddy yields, and that the initial period of accelerated glacier melt, which can temporarily increase downstream flow, is expected to give way to reduced long-term water availability as glacial ice reserves diminish further.

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Climate-adaptation proposals discussed in recent policy commentary include development and promotion of climate-resilient, short-duration crop varieties; expansion of rain- and snow-melt water-harvesting infrastructure with proper storage and conveyance, an intervention specifically recommended by national agricultural research authorities for J&K (ICAR, 2022); wider adoption of precision and automated irrigation technology; and crop-insurance and credit mechanisms tailored to the region's climate risk profile (Rising Kashmir, 2025). Longer-run modelling reinforces the urgency of these responses: ensemble climate-model projections for the J&K Himalaya to the end of the twenty-first century indicate continued warming and shifting precipitation regimes across the region's river basins, with direct implications for the timing and volume of irrigation-season water availability (Romshoo et al., 2020). Extreme events compound this gradual climatic, geomorphic and anthropogenic drivers combined to produce the catastrophic September 2014 Jhelum basin floods, which inundated large areas of agricultural land in the Kashmir Valley and illustrated how land-use change and reduced floodplain/wetland buffering capacity have amplified flood risk to irrigated cropland alongside the drought-side risks documented elsewhere in this review (Romshoo et al., 2018).

7.1 Groundwater and Springs as a Buffer — and Their Own Vulnerability

As surface-water and snowmelt-fed irrigation supply has become less reliable, groundwater and natural springs have taken on growing importance as a supplementary irrigation source across J&K, but the available hydrogeological literature indicates this buffer is itself under mounting stress. A geographic-information-system-based assessment of 258 springs across the Kashmir Valley found substantial variability in spring water quality and a general vulnerability of spring discharge to both regional hydrogeological conditions and anthropogenic pressure, underscoring that those springs cannot be assumed to provide a stable fallback irrigation source as glacier- and snow-fed streams decline (Bhat et al., 2022). District-level groundwater studies in Jammu division tell a similarly mixed story: assessment of the Tawi river basin found the pre-monsoon groundwater table had declined to roughly 26 metres below ground level in parts of the basin, a marked deepening relative to 2018 levels, consistent with intensifying groundwater draw-down for irrigation and domestic use (Roy et al., 2023), while a parallel hydrochemical survey of the Kathua region found groundwater generally suitable for drinking but locally unsuitable for irrigation where sodium concentrations were elevated (Kouser et al., 2022). A broader household survey across five Jammu-division districts found groundwater-level trends were spatially mixed, rising in some monitoring wells by over 13 metres and declining in others by up to 3.5 metres over the preceding decade, and identified seasonal variation, global warming and over-extraction as the three most commonly cited drivers of water scarcity by surveyed farming households (Verma et al., 2025).

The groundwater dimension of climate stress is not confined to the Kashmir Valley and Jammu plains. In Ladakh, a cold-arid trans-Himalayan region administratively separated from J&K in 2019 but hydrologically and agriculturally linked to the same glacier systems, groundwater reserves that irrigate barley, apricot and vegetable cultivation have been assessed as declining due to a combination of glacier retreat with glacier area and volume estimated to have shrunk by roughly 40% and 25%, respectively, since the Little Ice Age and rapidly rising anthropogenic water demand from population growth and tourism-driven urbanisation (Dar et al., 2024). Reporting on this research has noted that the Leh region's

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population grew roughly fivefold over the twentieth century, with built-up area expanding especially sharply in the last decade, intensifying pressure on a groundwater resource base that remains comparatively understudied relative to its growing importance for irrigated agriculture in the cold desert (Mongabay India, 2024).

8. Institutional and Governance Dimensions

The governance of irrigation systems has a demonstrable bearing on realised productivity and equity outcomes independent of physical infrastructure. Comparative evaluation of government- and farmer-managed irrigation schemes in Kashmir found that well-functioning water committees, regular annual desiltation, and clear conflict-resolution mechanisms distinguished better-performing schemes, whether departmentally or community managed, and recommended that defunct or poorly managed farmer kuhls be transferred to departmental management while well-functioning kuhls continue under farmer ownership with technical and financial support from the Irrigation Department (Shaheen, 2011). This nuanced finding that governance quality, rather than management model per se, is the stronger predictor of scheme performance has direct implications for the design of PMKSY-linked watershed and micro-irrigation interventions, which typically presuppose functioning local water-user institutions.

9. Synthesis and Research Gaps

Taken together, the reviewed literature supports three broad conclusions. First, irrigation coverage in J&K, while historically extensive by hill-state standards, has consistently lagged the levels achieved in India's major irrigated plains, and irrigation intensity (gross-to-net irrigated area) appears to have declined over 2010–2020, even as net irrigated area held relatively stable. Second, the productivity payoff from irrigation is strongest and most consistent for rice, where irrigation coverage is near-universal, but considerably weaker and more volatile for wheat and maize, which remain partly rainfed; productivity gaps are further shaped by on-farm water-management practice, fertiliser use and adoption of high-yielding varieties, not irrigation access alone. Third, the institutional quality of irrigation-scheme management rather than whether a scheme is farmer- or government-run appears to be a decisive but under-researched determinant of productivity and equity outcomes.

Several gaps limit the strength of these conclusions. Much of the available quantitative literature relies on state-level secondary statistics rather than farm-level panel data, limiting causal inference about the productivity effect of irrigation net of confounding inputs. Studies documenting climate-driven hydrological change are, to date, predominantly descriptive and drawn from recent journalistic and institutional reporting rather than peer-reviewed hydro-agronomic modelling specific to J&K's river basins. There is also a scarcity of post-2020 empirical productivity data, meaning the interaction between the accelerating climate trends documented in Section 7 and measured crop yields remains only partially quantified. Future research would benefit from district- or farm-level panel studies linking irrigation source (canal, kuhl, tube-well, lift) to yield outcomes, systematic evaluation of PMKSY-PDMC micro-irrigation uptake in J&K specifically, and integrated hydro-climatic modelling of snow- and glacier-fed river systems to project irrigation water availability under different climate scenarios.

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10. Conclusion and Policy Implications

Irrigation remains a foundational, though incompletely realised, driver of agricultural productivity in Jammu and Kashmir. The region's long tradition of community-managed gravity irrigation has been progressively supplemented and, in many areas, supplanted by departmental canal, lift and, increasingly, micro-irrigation infrastructure, yet net irrigated area still covers less than half of net sown area, and the productivity benefits of irrigation are unevenly distributed across crops and localities. Emerging climate pressures on snow- and glacier-fed water sources threaten to erode even these gains unless matched by proportionate investment in water storage, conveyance efficiency and climate-resilient agronomy. Policy priorities emerging from this review include: rehabilitating and better maintaining existing canal and kuhl/kool infrastructure; accelerating uptake of micro-irrigation technology under PMKSY-PDMC specifically in J&K's hill and valley districts; strengthening local water-user institutions regardless of formal management model; and investing in farm-level monitoring data to enable more rigorous future evaluation of irrigation's contribution to productivity growth in the region.

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