Sustainability of Water Interventions for Livelihoods in the Himalayas

A Dipstick Study of Supplementary Irrigation Interventions in the Western Himalayan Region of Uttarakhand

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Prepared for CEDAR, Dehradun

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Arun Pandhi
Director
August 28, 2026

Contents

Glossary

Terms, acronyms and local units of measure used throughout this report are defined below.

Term	Definition
CEDAR	Dehradun-based organization that commissioned this study on behalf of the IWMI-TATA Water Policy Research Program.
DTR	Detailed Technical Report — the engineering design document prepared for an irrigation scheme prior to construction.
Guhl	A traditional open, gravity-fed irrigation channel used across mountain Uttarakhand to carry water from a spring or stream to agricultural land.
HDAO	High-Density Apple Orchard — an intensive orchard planting system using closely spaced dwarf rootstock, generally irrigated by drip.
Himmotthan	An Associate Organization of the Tata Trusts, whose water interventions were examined in this study in Uttarakhand.
IWMI-TATA Water Policy Research Program	The Anand-based research program, funded jointly by the International Water Management Institute and the Tata Trusts, that funded this study.
Kharif	The monsoon-season crop cycle, sown around June and harvested around September-October.
KL	Kilolitre — 1,000 litres.
Lakh	100,000, in the Indian numbering system.
LDPE	Low-Density Polyethylene — a plastic sheet material used to line low-cost water storage tanks.
LPM	Litres per minute — the standard unit used in this report for source discharge.
Nali	The locally used unit of land measure in mountain Uttarakhand. One hectare comprises 50 Nali; one acre comprises 20 Nali.
Naula / Dhara	Traditional Himalayan water sources — a Naula is a stepped, stone-built spring structure, and a Dhara is a natural spring or its outlet.
O&M	Operation and Maintenance — the ongoing upkeep of an irrigation scheme after construction.
PoP	Package of Practice — a recommended, standardized set of agronomic practices for a given crop.
Quintal	100 kilograms, the standard unit used in this report for crop production.
Rabi	The winter crop cycle, sown around October and harvested around March.
RCC	Reinforced Cement Concrete — a common material for permanent water storage tanks.
Reserved Forest	Government-owned forest land under the direct control of the state Forest Department.
SARRA	Spring and River Rejuvenation Authority — the Uttarakhand government body formed to lead spring- and river-recharge conservation work.
Van Panchayat	A village-level forest council, and the community-managed forest land under its control.
WUG	Water User Group — the community body formed to operate, maintain and govern an irrigation scheme.

Chapter 1: Executive Summary

Water availability, not land, is the binding constraint on farm livelihoods across the mid-altitude Himalayan districts of Uttarakhand. More than four-fifths of cultivated land in the state's hill districts is rainfed[1], and rainfall itself is becoming less reliable: farmers across the study villages consistently reported shorter, more erratic monsoons and drier winters than a decade ago[2]. The consequence is visible on the ground: fields left fallow, working-age residents leaving for the plains, and a growing inventory of partially or wholly deserted hamlets that researchers have come to call Uttarakhand's “ghost villages.”[3] Small, well-targeted irrigation interventions — a diversion off a spring, a lift-irrigation pump powered by solar panels, a lined storage tank — are one of the few levers that can be pulled at the scale of an individual village to interrupt this cycle. The question this study set out to answer is not whether such interventions work, but whether they last, and what would make them last longer.

IWMI-TATA, under its Water Policy Research Program[4], commissioned this study — titled Sustainability of Water Interventions for Livelihoods — through CEDAR, Dehradun. The assignment was carried out by a team from Pandhi Green Solutions & Innovations Pvt. Ltd. (PGS), Dehradun, between September 2025 and February 2026. Its objective was to independently examine the efficacy, effectiveness, efficiency and impact of a representative set of water interventions in the Western Himalayan region, viewed through the lens of a changing climate, and to assess their potential for replication and scale. The study examined three broad categories of intervention:

- Support-irrigation schemes — gravity-fed systems, solar- and petrol-powered lift irrigation, and rainwater harvesting — that supplement rainfed cultivation during dry spells.
- Water storage structures, including UV-resistant LDPE-lined tanks, ferro-cement tanks, RCC tanks and geomembrane tanks, used to bank water for use between deliveries.
- Water distribution systems that move stored water from tank to field, whether by open pipe, drip or sprinkler.

[1]The World Bank's 2014 appraisal of the Uttarakhand Decentralized Watershed Development (Rainfed Farming) project describes eight mid-Himalayan districts where degraded, rain-dependent land is concentrated among poor, smallholder households with small and scattered holdings — the same structural conditions this study encountered in its twelve study villages. World Bank, "Agreement to Enhance Agriculture in Rainfed Areas of Uttarakhand," press release, 30 May 2014 (worldbank.org).
[2]Farmer-reported shifts in seasonality are consistent with the broader climate literature on Uttarakhand, which documents rising frequency of erratic rainfall and dry spells and links these changes directly to farm-level distress and out-migration. See Scroll.in, "In Uttarakhand, climate change is already forcing farmers to migrate," and Dialogue Earth, "Climate change forces Uttarakhand farmers to migrate" (scroll.in; dialogue.earth).
[3]Uttarakhand's Rural Development and Migration Commission has documented sustained out-migration from hill districts over the past two decades; independent reporting has since mapped hundreds of villages with declining or zero permanent population. See Mongabay-India, "Transforming a ghost village affected by climate change and migration," and Springer Nature, "Remote Sensing of 'Ghost Villages': The Challenge of Rural Migration in the Mountainous State of Uttarakhand, India" (india.mongabay.com; link.springer.com).
[4]The IWMI–Tata Water Policy Research Program is a joint initiative of the International Water Management Institute (IWMI) and the Tata Trusts, based in Anand, Gujarat, that has supported applied water-policy research across India for over two decades. See IWMI, "IWMI-TATA Water Policy Program" (iwmi.org/projects/itp).

1.1 Study Design and Village Selection

Twelve villages were selected across six mountain districts of Uttarakhand — three each in Pauri Garhwal and Dehradun, two each in Tehri Garhwal and Uttarkashi, and one each in Nainital and Almora — together with one unirrigated village, Nald, retained as a rainfed comparison case. Preference was given to villages where interventions had been operating for three to five years and had already been handed over to the community for operation and management, so that the study could observe how schemes actually behave once external project support tapers off, rather than only how they perform at commissioning. Selection was further guided by the type of water source and its catchment characteristics (Reserved Forest, Van Panchayat or civil/private land), discharge and storage capacity, topography-appropriate intervention type, land-use pattern (consolidated or fragmented), cropping pattern, and the scale of investment and institutional arrangement already in place.

1.2 Methodology

The study combined secondary and primary research. Secondary sources included Detailed Technical Reports (DTRs), drip and sprinkler manuals, prior case studies, progress reports and rainfall records. Primary data collection involved intensive field visits to each study village to observe irrigation infrastructure, land use and cropping patterns, institutional arrangements and operation-and-maintenance (O&M) status at first hand, supplemented by household- and village-level surveys and semi-structured interviews. Findings were triangulated through discussion with technical experts and cross-checked against secondary records.

The fieldwork window fell largely within the monsoon season, when farmers in the region typically do not irrigate — a limitation discussed further below — so a number of findings rely on farmers' recall of the preceding cropping season rather than on real-time measurement. This is the principal reason the study team recommends a second, concurrent phase of primary data collection spanning the full agricultural calendar.

1.3 Key Findings

1. Water Ecosystem

- Catchment protection is the weakest link in source sustainability. Catchments in Reserved Forest — largely unmanaged and unprotected — recorded an average 38.3% decline in source discharge relative to levels measured when the intervention was first commissioned; catchments in protected Van Panchayat forest declined by a comparatively modest 14.2%. The single village that had actively identified and treated its recharge zone, Saabli, recorded a 38% *increase* in discharge over the same period — the clearest evidence in the study that catchment treatment, not just infrastructure, determines whether a source survives. This pattern is consistent with the wider crisis facing Himalayan springs: a 2018 NITI Aayog working-group assessment found that nearly half the perennial springs across the Indian Himalayan Region show declining discharge, with the figure exceeding 80% in parts of Almora district — one of the six districts covered by this study[5].
- Most gravity-friendly sources close to habitations have already been tapped. The remaining untapped potential lies in sources below the level of settlements and farmland, which can only be reached by lifting — making solar-powered lift irrigation, sized to local topography, the more promising avenue for future schemes, given that it carries no recurring fuel cost against the roughly Rs. 1,080 a petrol-driven pump costs to run for an eight-hour day.

[5]NITI Aayog, Report of Working Group I: Inventory and Revival of Springs in the Himalayas for Water Security (2018), as summarized in Down To Earth, "Crisis in the Himalayas: Nearly 50% perennial springs in the region have dried up" (downtoearth.org.in). The Almora figure — a decline from roughly 360 functional springs to about 60 over some 150 years — is drawn from the same source.

- Storage capacity is frequently a guess rather than a design. In several villages (Diusa, Saabli), tank sizing was fixed early, on preliminary data, rather than against measured source discharge — leaving some tanks under-filled and others overflowing. Farmers' own preference has converged on a 20–30 KL underground ferro-cement or RCC tank as the best trade-off between cost, durability and seismic safety, but further piloting is needed to confirm this is the right default for all mountain conditions.
- Upland villages without any nearby water source remain entirely dependent on rainfed agriculture, and represent the least-served segment of the study sample; rainwater harvesting, at present used only opportunistically, deserves dedicated piloting for these locations.
- Distribution, not just supply, is where efficiency is being lost. Investment to date has concentrated almost entirely on the supply side — the source, the storage tank — while the last-mile distribution system for crop irrigation has received comparatively little attention. Most farmers still irrigate by open pipe or flood method; an estimated 20–40% of water is lost to transmission and application inefficiency between tank and root zone, and drip adoption on vegetables has stalled because farmers find the frequent removal and reassembly of driplines across crop rotations impractical[6]. Optimizing water use at the point of application is the single largest untapped efficiency gain identified by this study.

2. Cropping Pattern and Crop Production

- Where water becomes available, farmers shift decisively toward cash crops. Gross cropped area under vegetables and spices rose sharply after irrigation was introduced, and crop productivity increased by roughly 2 to 2.5 times across the vegetable-growing study villages; per-household farm income rose by 5 to 10 times in villages that adopted supplementary irrigation, compared with pre-intervention levels.
- Consolidated landholdings convert more readily to cash crops than fragmented ones. In Kyara, where land is largely consolidated, a much higher share of cultivated area went under cash crops than in Monisakri, where holdings are fragmented; in Diusa, women's groups overcame fragmentation through collective ‘group farming’ on adjoining fragmented parcels, suggesting a replicable institutional workaround where land consolidation itself is not feasible.
- In the three villages still dominated by cereal-based mixed cropping (Rampur, Saabli, Simoldi), average landholding is only about 5 Nali per household, and irrigation raised crop production by a comparatively modest 1.5 to 2 times — useful, but far below the gains seen where farmers converted fully to cash crops. The unirrigated comparison village, Nald, recorded per-household farm income of just Rs. 18,300 a year, against Rs. 3,29,770 in Chopriyalgaon, the highest-earning intervention village — an eighteen-fold gap that is the clearest single indicator in this study of what irrigation is worth to a mountain household.
- Rising cash-crop production is not cost-free. Reliance on purchased seed, fertilizer and pesticide is increasing, dosages are rising in the absence of extension advice on integrated pest and nutrient management, and organic manure use is declining alongside falling livestock numbers. Wildlife damage — and the cost of fencing against it — is a recurring constraint on cash-crop adoption that irrigation alone cannot solve.

3. Investments, Institutions, Efficiency and Sustainability

[6]Field-scale studies of drip irrigation in India and elsewhere consistently report water savings in the order of 30–50% relative to flood irrigation across a range of crops — for example, roughly 34% for winter wheat and 36–40% for maize — though basin-scale reviews caution that such field-level efficiency gains do not always translate into net water conservation once return flows are accounted for. See MDPI Water, "From Flood to Drip Irrigation: A Review of Irrigation Modernization Trade-Offs" (mdpi.com/2073-4441/17/20/3018).

- Community financial ownership remains thin. Across Himmotthan-supported interventions, the implementing program financed roughly 90% of scheme cost, with communities contributing about 10% — a ratio that, while consistent with sector norms for pilot-stage subsidy, leaves limited grounds for the accountability and self-repair behaviour that sustains a scheme once external support end. Farmers interviewed for this study were, encouragingly, more willing to raise their own contribution now that they have seen irrigation's effect on their income than they were before the intervention.
- Where landholding is consolidated or a scheme is individually owned, operation and maintenance is simpler and disputes are rare. Where holdings are fragmented, Water User Groups (WUGs) have generally stepped in to manage schemes collectively, though monthly tariff collection is unpopular in months when irrigation is not in use, and unresolved disagreements over dues are a recurring source of friction. A shift to crop-season-based tariff collection, tied to the timing of farm income, is a low-cost institutional fix this study recommends.
- Gender roles in scheme governance vary sharply by village and appear to track how central women are to marketing decisions, not just cultivation. In Diusa and Taliya, women hold a strong position in WUG decision-making and in marketing produce; in Kyara and Saabli, women's role remains confined to cultivation. Expanding WUG mandates to include agronomic planning and marketing — not only irrigation O&M — is identified as an opportunity to both improve scheme performance and widen women's economic agency.
- Infrastructure sited along streams and rivers is exposed to flash-flood risk that dedicated catchment work cannot mitigate. Solar lift schemes at Simoldi and Kyara were both damaged by flash floods within the study period, and in Simoldi's case the community has since lost interest in repairing the solar pump because the state's minor irrigation department has begun restoring an older gravity channel (Guhl) as an alternative — a reminder that sustainability planning must weigh climate risk to the asset itself, not only to the water source it draws from.
- Coordination with the Uttarakhand government's newly constituted Spring and River Rejuvenation Authority (SARRA) is identified as a priority. SARRA was established to lead the scientific identification, treatment and protection of spring recharge zones and traditional water sources (Dhara and Naula) across the state[7], and is a natural partner for exactly the kind of geohydrological mapping and recharge-zone treatment this study finds most study villages still lack.

1.4 Limitations of the Study and the Case for a Phase II

This study was necessarily conducted during the monsoon, when farmers across the study villages generally do not irrigate — soil moisture is ample and the kharif crop is being harvested — so it missed both the peak cropping season (March–November) and the peak crop-irrigation season (March–June). Findings on water use, crop production and income are therefore drawn predominantly from farmer recall and structured discussion rather than concurrent measurement. This is a genuine constraint on precision, but it is also, in the study team's view, a solvable one: A Phase II of primary data collection running from March to November 2026 would validate and sharpen the findings reported here, and — more importantly — generate the field-tested evidence needed to influence irrigation policy and design at scale. Phase II should prioritize three areas of action research: rainwater harvesting, storage and distribution for genuinely rainfed conditions; solar lift

[7]Government of Uttarakhand established the Spring and River Rejuvenation Authority (SARRA) in 2025 to lead scientific, participatory watershed management for the state's springs, streams and rivers, including its community-facing "Jal Sanrakshan Abhiyan" campaign. See ANI, "Uttarakhand government constitutes Spring and River Rejuvenation Authority to revive water sources" (aninews.in) and SARRA, Government of Uttarakhand (sarrauk.in).

pumps of varying capacity, matched to appropriate storage and O&M design; and water-efficient distribution systems paired with improved agronomic practice, to reduce production cost while protecting the biodiversity and soil health on which mountain farming ultimately depends.

Chapter 2: Background

Terraced agricultural land in a mid-altitude Himalayan valley, Uttarakhand — the setting for this study's twelve village case studies.

The central Himalayan region of Uttarakhand is the source of major river systems that sustain the Indo-Gangetic plains, yet the region itself experiences chronic, uneven water distribution and localized scarcity, particularly in its mid-altitude mountain areas. Rising frequency of extreme climate events — erratic rainfall, prolonged dry spells and intensified soil erosion[8] — is compounding these pressures, degrading soil quality and increasing the vulnerability of standing crops. Over 80% of the cultivated area in Uttarakhand's mountain districts is rainfed, and the rural population remains overwhelmingly dependent on subsistence agriculture for its livelihood. As rainfed farming becomes less reliable, out-migration from hill villages has accelerated, and the area of cultivable land left fallow or converted to wasteland continues to expand.

Addressing these challenges and building sustainable irrigation capacity in rainfed areas calls for a range of strategies and technologies that jointly improve water availability and agricultural water-use efficiency. Participatory action research on both traditional and modern irrigation systems is essential to identify what is already working, and where the gaps lie, before public and philanthropic capital is committed at scale.

2.1 Study on the Sustainability of Water Interventions for Livelihoods

This dipstick research study, titled Sustainability of Water Interventions for Livelihoods, analyzed the efficacy, effectiveness, efficiency and impact of a purposively selected set of water interventions in the Western Himalayan region, in the context of climate change and their potential for future scale. Three categories of intervention, each widely implemented across the Himalayan region by Himmotthan over the past decade, were examined:

- Water storage structures — UV-resistant plastic-lined (LDPE) tanks, ferro-cement tanks, RCC tanks and similar structures — used for support irrigation.
- Solar-based lift irrigation schemes and, where solar is impractical, petrol-driven lift pumps.
- Soil-moisture conservation and management practices appropriate to rainfed conditions.

In most locations studied, the water captured through these interventions is used to provide supplemental irrigation to horticultural and vegetable crops. This assignment was carried out by a team from Pandhi Green

[8]Farmer and field-team observations of erratic rainfall recorded in this study align with independent reporting on climate-linked agrarian distress in Uttarakhand's hill districts. See Dialogue Earth, "Climate change forces Uttarakhand farmers to migrate" (dialogue.earth).

Solutions (PGS) and ran in parallel with the IWMI-TATA Water Policy Research Program's wider programme of work on springshed management and drinking-water sustainability.

2.2 Scope of Services

The study's methodology comprised the following elements:

- **Site Selection:** Study villages across Uttarakhand were selected to represent a spread of topographic, climatic and intervention types (see Selection of Study Villages, below).
- **Before-and-After Mapping:** Pre- and post-intervention scenarios were mapped for each study village, with nearby control sites selected for comparison where feasible.
- **Research Methodology:** A structured framework was developed for data collection and analysis. Because primary data collection could not be timed to capture a complete agricultural season within the study's timeline, farmer recall data was used to reconstruct water inflows and utilization across seasons; a subsequent phase has accordingly been requested to collect primary data across the full February–November cropping cycle, which will validate and extend the findings of this study.
- **Water Ecosystem:** Water ecosystems were examined with particular attention to water utilization and its efficiency and effectiveness.
- **Cropping Pattern:** Vegetable and spice cropping patterns and practices were studied to identify constraints and recommend solutions that improve water utilization and productivity while lowering production cost.
- **Costing:** The cost of each intervention type was analyzed, along with its demonstrated effectiveness, funding sources and potential for scale.

2.3 Selection of Study Villages

Study villages were selected against the following criteria, in preference for locations where interventions had already been handed over to the community for operation and management:

1. Topographic and climatic conditions of the area — altitude, aspect, soil type, rainfall pattern and rain-shadow effect — such that the study sample represents temperate, mid-altitude and valley conditions within the mountain region.
2. Type of water source — natural spring, perennial stream or river — and the character of its catchment (Reserved Forest, Van Panchayat/Civil-Soyam land, or private/barren land).
3. Water discharge at source (in litres per minute) and the water storage structure built at the source.
4. Topography- and geography-appropriate water interventions — gravity-based, lift-based or rainwater harvesting — carried out for irrigation.
5. Water storage structures constructed for storage, such as LDPE, ferro-cement, RCC or geomembrane tanks.
6. The water distribution system adopted for irrigation — pipe, drip or sprinkler.
7. Land-use status — consolidated or fragmented — in the study village.
8. Crops and cropping pattern — vegetables, orchards, cereals or intercropping — and whether production is for subsistence or commercial sale.
9. Investment incurred in the intervention, the status of community institutions (community- or individual-managed), and the institutional mechanism for operation and management.

A total of twelve villages, including one unirrigated village retained for comparison, were selected across six districts: three villages each in Pauri Garhwal and Dehradun, two each in Tehri Garhwal and Uttarkashi, and one each in Nainital and Almora.

Table 2A — Selection of Study Villages

Village	Block	District	Inter-vention Year	Catchment Area	Water Source	Water In-tervention	Distribu-tion	Cropping Pattern
Diusa	Dwarikhal	Pauri Garhwal	2021-22	Reserved forest	Stream	Gravity	Pipes	Vegetables
Monisakri	Duggada	Pauri Garhwal	2020-21	Civil, private land	Spring	Solar lift	Pipes	Vegetables
Utirchha	Duggada	Pauri Garhwal	2021-22	NA	NA	NA	Pipes	Vegetables
Kyara-Badait	Raipur	Dehradun	2021-22	Reserved forest	Stream	Gravity & solar	Pipes	Vegetables
Pujargaon	Raipur	Dehradun	2022-23	Van Pan-chayat	Spring	Gravity	Drip	Apple orchard
Silla	Raipur	Dehradun	2021-22	Reserved forest	Stream	Petrol pump	Pipes	Vegetables
Saabli	Thatyur	Tehri Garhwal	2023-24	Van Pan-chayat	Spring/stream	Gravity	Pipe-sprinklers	Cereals
Chopriyal-gaon	Chamba	Tehri Garhwal	2022-23	NA	Rainwater, tap water	Rainwater harvesting	Drip, sprinkler	Intercropping
Taliya	Kotabagh	Nainital	2020-21	Van Pan-chayat	Spring	Gravity	Pipes	Vegetables
Rampur	Chaukhuti ya	Almora	2021-22	Private land	Marshy land	Solar lift	Pipes	Cereals
Simoldi	Bhatwari	Uttarkashi	2021-22	Reserved forest	River	Solar lift	Pipes	Cereals
Nald	Bhatwari	Uttarkashi	NA	NA	Unirrigated	NA	NA	Mixed (rain-fed)

- Two of the twelve villages received interventions delivered by the state government's line departments: a high-density orchard with drip irrigation under the Horticulture Department's Apple Mission (Chopriyalgaon, Tehri Garhwal), and a solar lift-based scheme with a 5-kW surface pump and 25 KL storage tank installed by UREDA (Kyara, Dehradun).
- The remaining ten villages were selected from Himmotthan-supported interventions, four of which involved convergence work with government line departments.

2.4 Village Selection by Intervention Type

Study villages were also selected to represent the following combinations of irrigation scheme, storage and cropping system:

10. Gravity schemes with differing storage tank types: five schemes across Diusa, Saabli, Utirchha, Pujargaon and Taliya.
11. 5 kW solar lift irrigation schemes with two pump configurations: submersible pumps at Monisakri and Rampur; surface pumps at Kyara and Simoldi.
12. Honda petrol-driven lift pumps (5 HP): Silla and Rampur.

Villages were further differentiated by cropping system: intercropping of orchard with vegetables (Pujargaon, Chopriyalgaon); vegetable- and spice-based high-value crop production (Kyara, Diusa, Monisakri, Taliya, Silla, Utirchha); cereal-dominated mixed cropping (Rampur, Simoldi, Saabli); and rainfed subsistence production (Nald).

2.5 Methodology

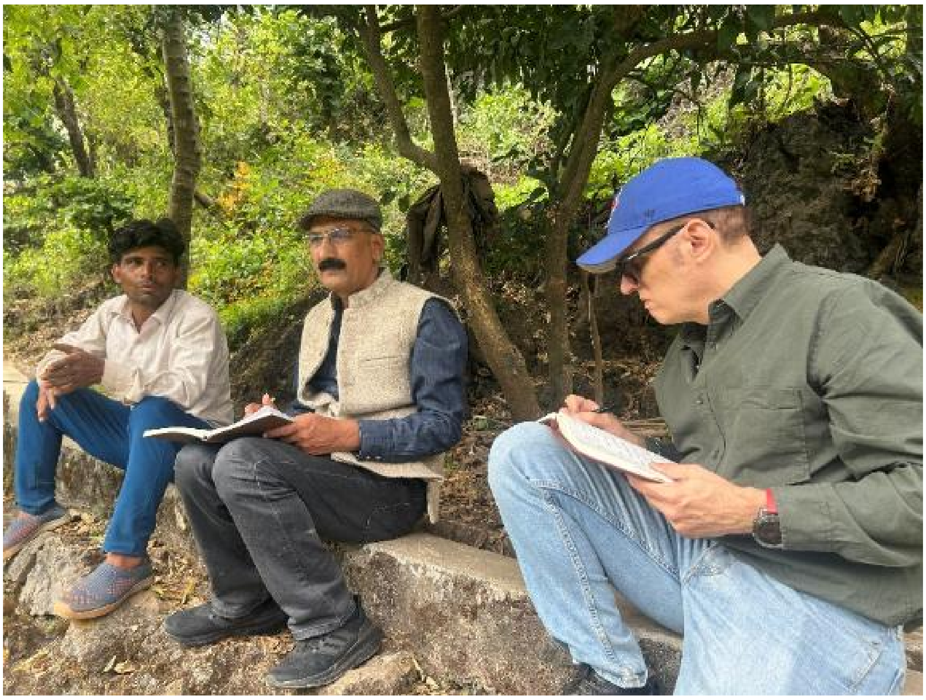
Secondary Data

Secondary data collection comprised the compilation of Detailed Technical Reports (DPRs), drip and sprinkler manuals, prior case studies, progress reports and rainfall records.

Field Visits and Primary Data Collection

Intensive field visits were undertaken in each study village to observe irrigation interventions, land use and cropping patterns, institutional structures and O&M status at first hand. Village-level data was collected through a structured survey format, supplemented by semi-structured interviews and discussions with stakeholders, and by direct observation of records maintained at the village level. The data-collection checklist used in the study villages is provided in Annexe 1.

The study team recording field data with a farmer during a village visit, November 2025.



Members of the study team in discussion with a farmer during a village visit.

A focus-group discussion with village women, held during the field survey.

The study team walking a terraced field during a village visit.

Triangulation of Field Data

Field findings were triangulated through discussion with different stakeholders and technical experts, and cross-verified against compiled secondary data.

2.6 Report Structure

This report is organized as follows:

- **Chapter 1 — Executive Summary:** a condensed account of study design, methodology, key findings and headline recommendations, together with the principal limitations of this round of fieldwork and the case for a Phase II.

- **Chapter 2 — Background:** the study's origin and terms of reference, the criteria used to select study villages, the field methodology, and the limitations of a study conducted during the monsoon season.
- **Chapter 3 — Water Ecosystem:** catchment area, source availability, topography-based interventions, storage capacity and water distribution for irrigation, examined across gravity-based, lift-based and rainwater-harvesting subsets and their permutations, from the standpoint of source sustainability, storage and distribution efficiency.
- **Chapter 4 — Cropping Pattern & Crop Production:** yield and productivity, before-and-after comparisons, cost of production, and scope for improvement (wildlife damage, soil health and moisture, and dissemination of package-of-practice knowledge).
- **Chapter 5 — Investments, Institutions, Efficiency and Sustainability of Interventions:** institutional arrangements; ownership and O&M models — hardware and software — community contribution and governance, including conflict-resolution mechanisms; and the sustainability of water sources, storage, distribution networks and the agricultural and horticultural production they support.
- **Chapter 6 — Recommendations:** consolidated recommendations for models suited to upscaling.
- **Chapter 7 — Case Studies:** village-by-village case studies illustrating the range of intervention combinations encountered across topographic and geographical settings, and the corresponding variation in cropping pattern.

Note: given the very small average landholding in Uttarakhand's mountain villages, land-related data throughout this report is presented in Nali, the locally used unit of measure. One hectare comprises 50 Nali; one acre comprises 20 Nali.

2.7 Limitations of the Study

The study was carried out during the monsoon season, a period in which farmers generally do not irrigate their fields, owing to ample soil moisture and the ongoing harvest of kharif crops. This gives rise to the following principal limitations:

- The study window missed both the peak cropping season (March–November) and the peak crop-irrigation season (March–June); primary data collection covering this period should be undertaken during 2026.
- Current findings rely substantially on farmer recall and structured discussion rather than concurrent measurement. The study has nonetheless identified specific gaps that warrant further action research using primary field data.
- A concurrent Phase II is accordingly considered essential to validate and extend this study's findings.

Chapter 3: Water Ecosystem

A gravity-fed irrigation storage tank in one of the study villages.

3.1 Background

This chapter examines the Himalayan water ecosystems that underpin supplementary irrigation in the study villages: catchment areas and water availability at source and their sustainability; topography-appropriate intervention types; storage capacity; and irrigation-distribution systems. It draws on gravity-based, lift-based and rainwater-harvesting interventions, and the permutations and combinations in which they occur, and views each through the lens of efficiency and effectiveness across three dimensions:

- Source sustainability and optimal utilization of the source.
- Storage.
- Distribution.

Each intervention was assessed during field visits to the relevant study village, and each village is treated as a case study in its own right in Chapter 7, from which the scenarios discussed here are drawn. In broad terms, a water ecosystem for irrigation comprises the catchment area and water source, discharge at the source, topography-based interventions, water storage and a water distribution system for irrigation.

3.2 Catchment Area and the Water Source

The catchment areas feeding the study villages' water sources fall into three broad categories: Reserved Forest, Van Panchayat forest, and civil or private land (Table 3A).

Table 3A — Catchment Area and Water Source

Village	Block	Catchment Area	Area (Ha)	Water Source	Catchment Area Status
Diusa	Dwarikhal	Reserved forest	NA	Khola stream	Unprotected, degraded forest
Monisakri	Duggada	Civil, private land	40	Spring	Barren land, unprotected; no treatment
Utirchha	Duggada	NA	NA	NA	Multiple villages' drinking-water source; catchment not known
Kyara-Badait	Raipur	Reserved forest	NA	Bandal stream	No treatment, unprotected; high flash-flood risk
Pujargaon	Raipur	Van Panchayat	50	Spring	Broadleaf forest, well protected by the community
Silla	Raipur	Reserved forest	NA	Stream	Unprotected and untreated; high flash-flood risk
Saabli	Thatyur	Van Panchayat	9	Paniyarkhala spring	Recharge zone identified; 4.75 ha treated and protected
Chopriyalgaon	Chamba	NA	NA	Stream	Surkanda drinking-water lift-pump source; catchment not known
Taliya	Kotabagh	Van Panchayat	58	Sarkapani spring	Broadleaf forest, well maintained by the community
Rampur	Chaukhutiya	Private land	NA	Marshy land	Catchment not identified; no treatment
Simoldi	Bhatwari	Reserved forest	NA	Asiganga River	Water lifted from river; large catchment area

3.2.1 Catchment Areas in Reserved Forest

The water sources in Diusa, Kyara, Simoldi and Silla are either perennial streams or rivers whose catchment areas span a large valley, most of which falls under the Reserved Forest category. In Diusa, the Khola stream originates roughly 10 km above the village, and numerous drinking-water schemes have already been drawn off it; its catchment is untreated and unprotected. In Kyara-Badait, the Bandal stream originates about 12 km above the village in a Reserved Forest catchment that receives neither treatment nor protection, producing a sharp fall in streamflow through the summer and a high flash-flood risk during the monsoon. Silla's stream, originating below Suwakholi top some 12 km upstream, follows the same pattern of degraded, unprotected forest, seasonal decline and flash-flood exposure. In Simoldi, water is lifted from the Asiganga River, whose flow varies markedly between peak and lean seasons and whose catchment — again largely Reserved Forest — carries a major flash-flood risk.

3.2.2 Catchment Area in Van Panchayat Forest

The water sources in Pujargaon, Taliya and Saabli are natural springs originating within Van Panchayat forest. In Pujargaon, three springs rise in a well-protected, community-managed broadleaf forest above the village and are tapped into a collection chamber. In Taliya, the spring rises about 4 km from the village in a similarly well-maintained broadleaf forest; although its recharge zone has not been formally identified or treated, seasonal variation in flow is comparatively small. Saabli is the exception that proves the rule: here the recharge zone has been identified and roughly 4.75 hectares of catchment treated and protected by the village community with Himmotthan's support, through a combination of engineering and vegetative measures — and it is the only study village where source discharge rose rather than fell over the study period.

3.2.3 Catchment Area in Private and Civil Land

In Monisakri, the spring originates 80–85 metres below the village on barren, degraded civil and private land with limited scope for rainwater percolation; villagers report a rapidly declining discharge. In Rampur-Chaukhutiya, the source is a marshy area within private agricultural land, roughly 80 metres below the village near the riverbed; water is collected from several discharge points into an underground RCC tank, and discharge here remains comparatively stable through the year, though the catchment itself has not been identified.

3.2.4 Drinking-Water Tap Stands

Two villages draw supplementary irrigation water from surplus drinking-water supply rather than a dedicated catchment. In Utirchha, surplus water from the village drinking-water scheme is tapped and stored for irrigation. In Chopriyalgaon, an LDPE tank on agricultural land harvests rainwater with no defined catchment, supplemented by surplus water drawn from the Surkanda drinking-water lift scheme at a nearby tap stand and pumped into the LDPE tank.

A mid-altitude Himalayan catchment above one of the study villages — the source of the streams and springs on which supplementary irrigation depends.

3.3 Water Source Discharge

Comparing discharge recorded at the time each scheme's Detailed Technical Report (DTR) was prepared against discharge recorded during this study reveals a consistent pattern: discharge has fallen almost everywhere catchments remain untreated, and risen only where they have been treated.

- A 38.3% decline in source discharge was recorded in villages whose catchment lies in unprotected Reserved Forest (Diusa, Kyara, Silla).
- A comparatively smaller 14.2% decline was recorded where the catchment lies in protected Van Panchayat forest (Taliya, Pujargaon, Saabli, taken together).

- A 38.5% decline was recorded where the catchment lies in unprotected private or civil land (Monisakri, Rampur).
- Saabli, the one village where the catchment's recharge zone was identified and treated prior to the irrigation intervention, recorded a 38% increase in discharge over the same period — a striking reversal of the trend seen everywhere else.

Figure 3A — Catchment Area: Reserved Forest

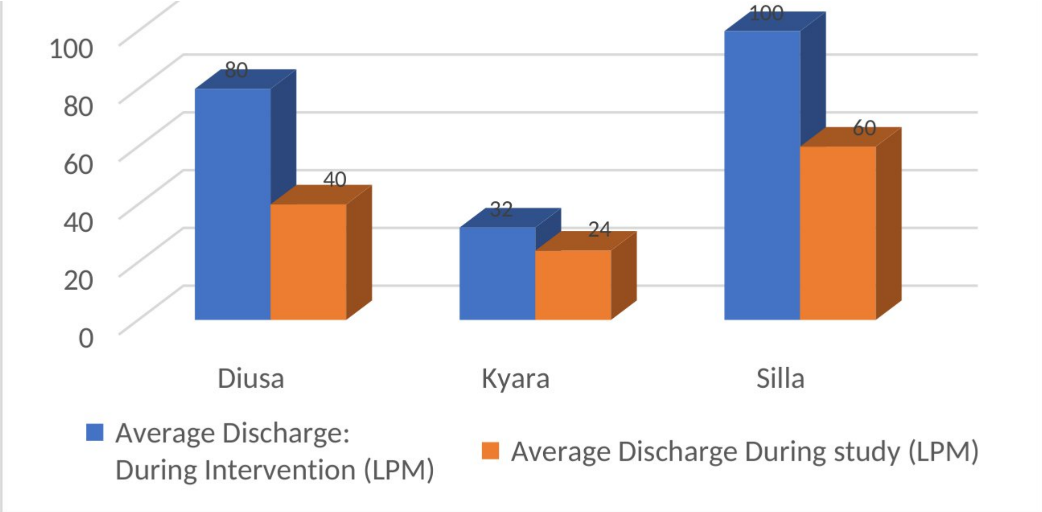


Figure 3B — Catchment Area: Van Panchayat Forest

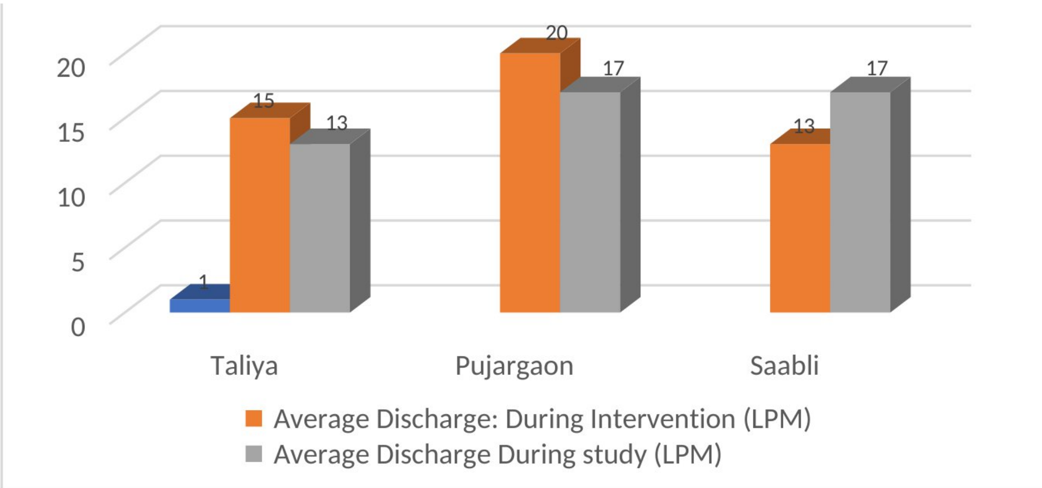
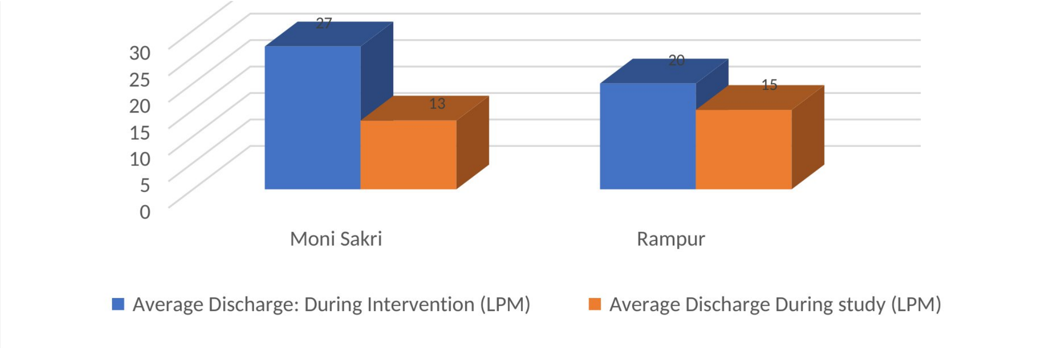


Figure 3C — Catchment Area: Private, Civil Land



Water User Committee (WUC) members across the study villages confirmed that discharge fluctuates through the year, particularly between lean and peak season, but that in recent years they have observed a steady underlying decline, with some villages now experiencing outright scarcity in the dry season. In Monisakri, villagers described a sharp fall in discharge from their age-old source and voiced concern that it could dry up altogether; they attributed this to the expansion of fallow land and the degradation of community land above the source, compounded by construction of a new link road through the catchment. WUCs in every village expressed a wish to arrest this decline but reported limited technical knowledge of how to identify and treat a recharge zone, leaving them entirely dependent on external technical assistance.

3.4 Topography-Based Water Interventions

Based on topography and source availability, three broad categories of irrigation intervention were implemented across the study villages: gravity-based schemes; solar- or petrol-powered lift irrigation; and rainwater harvesting.

3.4.1 Gravity-Based Irrigation Scheme

Drawing water by gravity from a source above the habitation is common practice across mountain Uttarakhand. Gravity-based schemes, in various combinations, were studied in five villages (Table 3B).

Table 3B — Gravity-Based Irrigation Schemes

Village	Storage at Source	Discharge (LPM)	Pipeline (m)	Tank Type	Capacity (L)	Water/Day (L)	Time to Fill Tank (Hrs)
Diusa	Intake chamber, protection wall	40	940	LDPE tank	25,000	57,600	10
Kyara-Badait	Diversion Guhl	36	350	RCC tank (3)	95,000	51,840	44
Pujargaon	Collection chamber	17	400 + 4,500 drip	Syntax tank (3)	5,500	24,480	5
Saabli	Intake chamber, protection wall	17	680	RCC tank	40,000	24,480	39
Taliya	Intake chamber, protection wall	13	4,200	LDPE tank	25,000	18,720	32

In Diusa, source discharge of 40 LPM makes 57,600 litres a day theoretically available, against a tank capacity of only 25,000 litres; farmers commonly bypass the tank altogether and connect directly to the pipeline when more water is needed. In Kyara, farmers relied before 2022 on a 30 KL RCC tank fed by gravity from the Guhl channel, giving roughly 9 lakh litres a month — enough to irrigate 60 Nali of land only over about 15 days each cycle; two additional tanks built since have lifted total storage to 95 KL, now sufficient for year-round irrigation. Pujargaon's three Syntax tanks (5.5 KL combined) sit atop the agricultural field and feed a drip system installed for the high-density apple orchard. In Saabli, water reaches a 40 KL RCC tank at the top of the agricultural parcel, taking an average of 39 hours to fill; in Taliya, a similarly positioned 25 KL tank takes about 32 hours.

3.4.2 Solar Power-Based Lift Irrigation

Solar-powered lift irrigation was studied in four villages: a 5 kW DC submersible pump in Monisakri and Rampur, and a 5-kW solar-powered surface pump in Kyara and Simoldi (Table 3C).

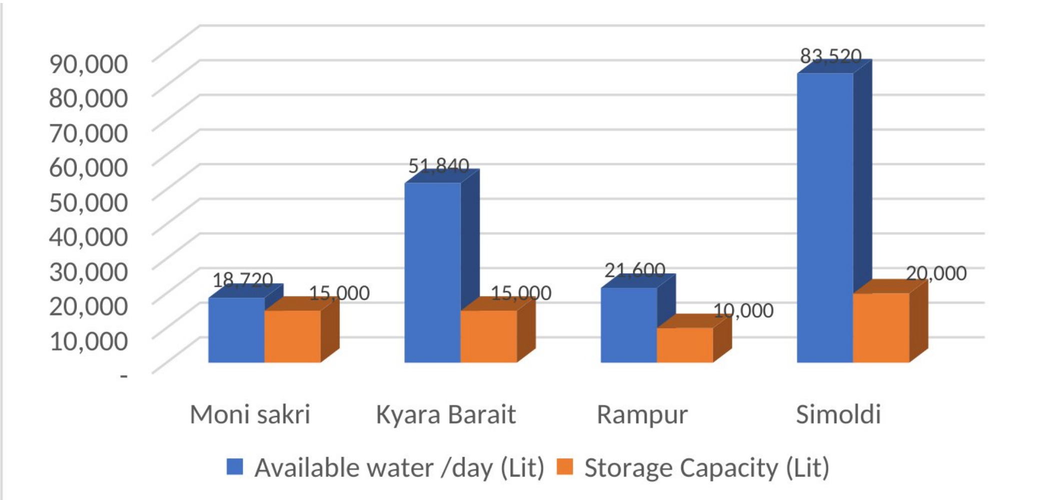
Table 3C — Solar Power-Based Lift Irrigation

Village	Storage at Source (L)	Discharge (LPM)	Water at Source (L/Day)	Head (m)	Pipeline (m)	Storage Tank	Tank Capacity (L)	Water/Day at Tank (L)	Configuration
Monisakri	15,000	13	18,720	70	850	Geomembrane tank	20,000	17,280	5 kW solar DC submersible pump
Kyara-Badait	15,000	36	51,840	60	800	RCC tank	25,000	19,200	5 kW solar surface pump
Rampur	10,000	15	21,600	34	600	1 RCC tank	20,000	19,200	5 kW solar DC submersible pump
Simoldi	20,000	58	83,520	31	600	Geomembrane tank	20,000	19,200	5 kW solar surface pump

In Monisakri, the 18,720 litres a day theoretically available at the source is well ahead of the 15 KL storage capacity built at the source; water-lifting efficiency here could be improved further through more regular maintenance of the submersible pump and solar panels. In Kyara, an intake chamber and diversion channel feed a surface pump that farmers install at the source only when water is needed, then remove and store at home between uses to guard against theft and flood damage. In Rampur, available water at source (21,600 L/day) again exceeds the 10 KL tank capacity, and collection could be further increased by tapping additional discharge points within the marshy source area. In Simoldi, water is lifted from the Asiganga River; the surface pump was damaged by a sudden flash flood in June 2025 and the scheme has been non-operational since.

Table 3D — Solar Lift Scheme: Water Availability vs Storage

Figure 3D — Water Discharge, Storage at Source



Village	Source Discharge (LPH)	Water Available/Day (L)	Storage Capacity (L)	Solar Water Lift (L/Day, 8 hrs)	Tank Storage (L)	Water Availability (L/Month)
Monisakri	780	18,720	15,000	17,280	20,000	5,18,400
Kyara-Badait	2,160	51,840	15,000	19,200	95,000	5,76,000
Rampur	900	21,600	10,000	19,200	30,000	5,76,000
Simoldi	3,480	83,520	20,000	19,200	40,000	5,76,000

High-density apple orchard with solar fencing.

3.4.3 Petrol-Driven Honda Water Pump

Petrol-driven pumps are individually owned, operated by farmers as needed for irrigation, with the owner responsible for O&M (Table 3E).

Table 3E — Petrol-Driven Honda Water Pump

Village	Source	Discharge (LPM)	HP/kW	Head (m)	Discharge (LPM)	Output/Hr (Nali)	Output/Day, 8 Hrs (Nali)
Rampur	River	>100	5.5/3.6	25–30	1,000	1–1.5	9
Silla	Stream	>50	5.5/3.6	25–30	900	1–1.5	8

A 5.5 HP petrol-driven pump readily lifts water to a height of 25–30 metres, discharging around 900 litres an hour; run for eight hours a day, it can irrigate roughly 10 Nali of land, lifting 90,000 litres of water, at a total operating cost of approximately Rs. 1,080 a day (Table 3F) — a cost that makes solar-powered alternatives markedly more attractive wherever a recurring 8-hour operating window is required.

Table 3F — Operation and Maintenance of a Petrol-Driven Water Lifting Pump

Particular	Value
Fuel required per hour (L)	0.75
Estimated petrol cost per litre (Rs.)	80
Cost of fuel per hour (Rs.)	60
Cost of fuel per 8-hour day (Rs.)	480
Miscellaneous cost (Rs.)	100
Total per-day operating cost (Rs.)	1,080
Per-hour output, flood irrigation (Nali)	1.25
Per-day (8-hr) output, flood irrigation (Nali)	10
Approximate pumping capacity (L/hr)	9,000

Particular	Value
Total water pumped per day (L)	90,000
Cost per Nali irrigated (Rs.)	83

3.4.4 Rainwater Harvesting and Tap Stand Water for Irrigation

Collecting rainwater and storing surplus drinking-water tap-stand supply for irrigation is common practice in rainfed parts of Uttarakhand; two such villages were studied (Table 3G).

Table 3G — Rainwater Harvesting and Tap Stand Water for Irrigation

Village	Water Source	Storage Tank (L)	Discharge at Tap (LPM)	Water/Day (L)	Water/Month (L)	Water/Year (L)	Rainwater Harvested (~2 full tanks/yr)
Utirchha	Rainwater, tap water	10,000	6	360	10,800	86,400	20,000
Chopriyalgaon	Rainwater, tap water	67,000	9	540	16,200	1,29,600	1,34,000

In both villages, the drinking-water scheme runs for roughly an hour a day, and farmers use this window to top up storage tanks; farmers also report filling their tanks twice a year with rainwater, at the onset of the monsoon and again during the spring. Stored water is reserved for critical irrigation during the dry season.

Upstream villages such as Taliya and Saabli, which sit close to natural springs, have tapped sources above the habitation through gravity schemes for both drinking and irrigation use. Villages along perennial streams or rivers — Kyara, Diusa, Silla, Simoldi — draw on that flow directly. More recently, Monisakri and Rampur have begun tapping sources below the settlement for irrigation using solar- and petrol-driven pumps. Excessive upstream withdrawal has the potential to create water-equity issues for downstream villages; this question lies beyond the scope of the present study but merits a dedicated follow-up assessment.

3.5 Types of Water Storage Tanks for Irrigation

Six types of water storage tank are in common use in rural Uttarakhand. Based on discussion with technical experts, Table 3H compares estimated construction cost (for a 20 KL tank), per-litre cost and durability.

Table 3H — Comparison of Water Storage Tank Types

Tank Type	Construction Time (Days)	Est. Cost (Rs.)	Cost (Rs./L)	Durability (Years)
LDPE sheet-lined tank	4	30,000	1.5	3–5
Ferro-cement underground tank	5	35,000	1.75	8–10
Plastic tank*	0	10,000	5	8–10
Geomembrane tank	2	1,00,000	5	12–15
Masonry tank	10	1,40,000	7	15–20
RCC tank	20	1,50,000	7.5	30–50

* Cost shown for a 2,000-litre-capacity plastic tank.

- LDPE-lined tank: Rs. 1.5 per litre; easy to construct, but requires proper protection and maintenance.

- Ferro-cement underground tank: Rs. 1.75 per litre; best suited to smaller capacities and drip/sprinkler irrigation.
- Plastic tank: Rs. 5 per litre; ready-made and well suited to drip irrigation.
- Geomembrane tank: Rs. 5 per litre; easy to repair, but needs regular maintenance.
- Masonry tank: Rs. 7 per litre; requires stable ground, and is difficult to repair once leakage begins.
- RCC tank: Rs. 7.5 per litre; requires stable ground, as leaks on unstable ground are difficult to repair.

Table 3I — Strengths, Weaknesses and Annual Maintenance of Tank Types

Tank Type	Strength	Weakness	Annual Maintenance
LDPE sheet-lined	Good strength/durability, very low cost, quick to build, suitable for small/medium sizes, can be built by unskilled labour	Easily damaged by weathering and human activity; misuse by beneficiaries	Full top cover to reduce weathering/evaporation loss; fencing; cost Rs. 1,000–10,000
Ferro-cement underground	Good strength/durability, easy self-repair, low cost, quick to build, good for small sizes	Difficult to build at large capacity; easily damaged by weathering and human causes	Silt cleaning twice a year; plaster repair as needed; cost Rs. 1,000–5,000
Geomembrane	Widely used modern technology by government departments, well suited to irrigation, quick installation, low cost, good for medium storage, repairable by replacing material	Requires skilled technicians and firm, suitable land, not available everywhere in hilly terrain; easily damaged by people and animals; cost-effective mainly at scale	Silt cleaning twice a year; material replacement as needed; cost Rs. 2,000–25,000
Masonry	Built with locally available material, no shuttering required, semi-skilled labour, good for small/medium sizes	High construction cost; very difficult to repair if cracked; transport of bricks/stone difficult; easily weather-damaged	Silt cleaning twice a year; plaster and concrete repair; cost Rs. 2,000–30,000
RCC	Very high strength, leak-proof, resistant to weathering, human damage and minor seismic effects; best for large storage	High construction cost; cracking possible from foundation settlement under self-load; requires skilled technical guidance; difficult or impossible to repair against cracks	Silt cleaning twice a year; plaster, waterproofing and re-concreting as needed; cost Rs. 2,000–30,000

An underground storage tank feeding a terraced field, of the type farmers in this study consistently rated highest for durability and low maintenance.

3.5.1 Farmers' Preference Regarding Tanks

Farmers consistently prefer low-cost, durable tanks that can be built on their terraced fields with minimal maintenance. Field discussions point to the following consensus:

- A storage tank of 20–30 KL capacity is best suited to mountain topography, given its high seismic risk; larger tanks carry a greater risk of leakage.
- Farmers prefer underground tanks to above-ground tanks, and rate a half-underground, half-above-ground design more highly still, for its lower leakage risk and easier maintenance.
- LDPE-lined tanks, though low-cost, are prone to sheet damage, need regular maintenance and have a shorter service life.
- Farmers favour ferro-cement underground tanks over LDPE tanks for their durability and lower maintenance burden, at similarly low cost.
- Farmers favour RCC tanks over stone masonry tanks, for their durability and lower leakage risk.
- Geomembrane tanks are a recent addition — an above-ground variant of the ferro-cement tank that is easy to build but costly; farmers are still forming a view on their long-run performance.

Overall, farmers favour a moderate-sized underground ferro-cement and/or RCC tank; further piloting is nonetheless needed to confirm the best-suited tank type for mountain conditions and easy farmer adoption.

3.5.2 Types of Water Lifting Pumps

Different types of water-lifting pump suit different mountain irrigation contexts (Table 3J).

- Submersible pumps are used where the source is a natural spring: water collects in a storage tank and is then lifted by the submersible pump. They are easy to operate and carry lower maintenance costs, based on field experience.
- Surface pumps are used where the source is a perennial stream or river: water is diverted to an intake chamber and then lifted by surface pump to the storage tank. Siltation carries a high risk of pump damage, as does flash flooding.
- Petrol-driven pumps are generally used in valleys with ample stream or river flow. Being lightweight, they are easy to move between locations; a storage tank is generally not needed, but annual maintenance is required.

Table 3J — Specifications of Water-Lifting Pumps

Pump Type	HP/kW	Head (m)	Discharge (LPM)	Cost of Pump (Rs.)	Total Installed Cost (Rs.)
Submersible pump	2/1.5	30–70	40–120	1,25,000	3,15,000
Submersible pump	3/2.2	50–90	60–120	1,55,000	3,70,000
Submersible pump	5/3.7	30–120	90–470	2,00,000	4,40,000
Surface pump	2/1.5	22	450	90,000	3,00,000
Surface pump	3/2.2	24	900	1,20,000	3,60,000
Surface pump	5/3.7	26	1,200	1,50,000	4,30,000
Honda water pump	2/1.5	—	512	22,000	—
Honda water pump	5.5/3.6	—	1,100	32,000	—

Table 3K — Strengths, Weaknesses and Annual Maintenance of Pump Types

Pump Type	Strength	Weakness	Annual Maintenance
Solar-powered submersible	One-time installation cost, low operating cost, green technology, benefits from good sunlight	No local technical know-how; lack of a locally available technician; mishandling by beneficiaries	Regular cleaning and maintenance of pump and panel; fencing of the installation site; cost Rs. 5,000–25,000
Solar-powered surface	Good for valley areas with a perennial source below the village; green technology, low operating cost; portable between locations	Risk of monsoon-season damage; frequent pump/sump maintenance required; limited local technical knowledge	Silt cleaning twice a year; frequent repair of sump and diversion channel; cost Rs. 10,000–25,000
Honda petrol pump (28 kg)	Ready to use; high government subsidy available; well suited to villages near a stream/river; easy to move between locations	High operating cost; lack of a local technician for repair; regular maintenance cost	Maintenance required twice a year; cost Rs. 500–2,500

Farmers using solar-powered submersible pumps report being comfortable with system performance, though limited technical know-how occasionally leads to mishandling and damage. Surface pumps present more day-to-day difficulty, since they must be moved to and from the source each time water is lifted and are exposed to a high risk of siltation damage during the monsoon; the absence of nearby technicians or repair centres means even minor repairs are costly. Some valley farmers along perennial streams have instead purchased petrol-driven pumps, drawn by the substantial state subsidy on offer; being portable and simple to maintain, and used only in line with actual crop water needs, these pumps keep operating costs manageable.

3.6 Water Distribution System for Irrigation

A consistent observation across all study villages is that investment in supplementary irrigation has concentrated on the supply side — collecting water at the source, the diversion pipeline and the storage tank — while comparatively little work has gone into the distribution system that ultimately delivers water to the crop. Most farmers rely on open pipes for crop irrigation. Three broad types of distribution system were observed:

13. Drip-based irrigation in high-density apple orchards.
14. Pipe-based spray/surface irrigation in vegetables and cereals.
15. Sprinkler-based irrigation in vegetables and spices.

3.6.1 Drip-Based Irrigation in High-Density Apple Orchards (HDAO)

High-density apple orchards have been established in Pujargaon (Dehradun district) and Chopriyalgaon (Tehri Garhwal district). In Pujargaon, 13 farmers collectively established an orchard across 21 Nali of land, planting 1,350 'Gala' and 'Delicious' plants at 3-metre line spacing and 1-metre plant-to-plant spacing, and intercropping winter peas between rows. In Chopriyalgaon, a high-density orchard was planted on 26 Nali of land with 500 'Gala' and 'Delicious' plants at the same 3 m × 1 m spacing, alongside intercropped vegetables and spices.

Table 3L — Drip System in High-Density Orchards

Specification	Pujargaon	Chopriyalgaon
Year of intervention	2022-23	2021-22
No. of farmers	13	3
Land area (Nali)	21	26
Plant species	Gala & Delicious	Gala & Delicious
Plant spacing (line × plant, m)	3 × 1	3 × 1

Specification	Pujargaon	Chopriyalgaon
No. of plants/Nali	1,350	500
Length of drip system (m)	4,500	5,000
Mainline (HDPE pipe)	32 mm	32 mm
Lateral line (HDPE pipe)	16 mm	16 mm
No. of drips/Nali	66	66
Dripper spacing	1 dripper/plant	1 dripper/plant
Drip quality	Pressure-compensating	Normal
Dripper discharge (L/hr)	4	1

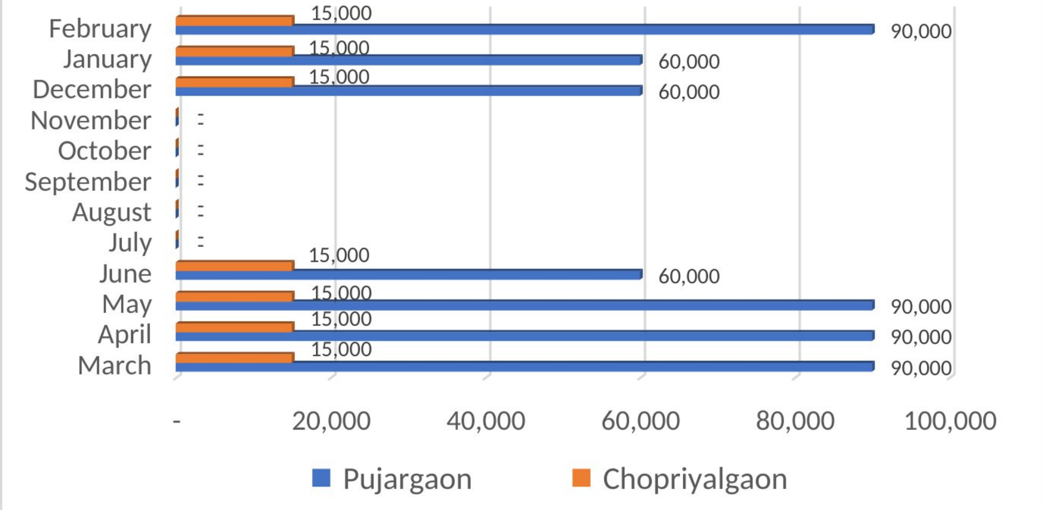
Pujargaon's three Syntax tanks (2,500 L combined capacity) sit atop the field and feed the pressure-compensating drip system; Chopriyalgaon's 25,000-litre LDPE-lined tank, filled from rainwater harvesting and drinking-water tap-stand surplus, feeds a normal-quality drip system delivering just 1 litre per hour per dripper.

A field technician fitting a drip lateral in a high-density apple orchard.

3.6.2 Irrigation in Orchards

In Pujargaon, a total of 540,000 litres of water was supplied by drip irrigation over seven months of the year, with no irrigation from July to November; supply peaked at 90 KL a month from February to May and in June, and fell to 60 KL a month in the remaining active months. In Chopriyalgaon, water scarcity limited annual drip supply to just 105,000 litres, averaging 15 KL a month over seven active months — roughly a fifth of Pujargaon's volume despite the larger planted area, underscoring how tightly source availability constrains this scheme.

Figure 3E — Monthly Water Supply for Orchards (Litre)



3.6.3 Irrigation in Intercropping with Vegetables

In Chopriyalgaon, despite the prevailing water shortage, farmers continue to provide critical spray irrigation to intercropped vegetables, using roughly 130,800 litres of water a year to maintain soil moisture. In Pujargaon, only the winter pea crop is grown beneath the orchard; farmers give it three pipe-spray irrigations between December and April, using around 30 KL of water (Table 3M).

Table 3M — Irrigation in Intercropping with Vegetables

Village / Crop	Irrigation Season	Method	Water Supplied (L/Nali)	No. of Irrigations	Area Covered (Nali)	Total Water Supplied (L)
Chopriyalgaon — Rabi vegetables	Dec–Apr	Pipe-spray	600	4	33	79,200
Chopriyalgaon — Vegetables	May–Oct	Pipe-spray	600	2	23	27,600
Chopriyalgaon — Jaid vegetables	Jul–Nov	Pipe-spray	600	1	40	24,000
Pujargaon — Rabi vegetable pea	Dec–Apr	Pipe-spray	5,000	3	20	3,00,000

Farmers are well acquainted with drip irrigation in orchards, where the system is installed once at establishment and continues to serve, largely maintenance-free, for the life of the orchard; farmers report it as a genuine labour- and water-saving device. The same farmers who tried drip on vegetable crops mostly abandoned it, citing the burden of removing and reassembling the system with each crop rotation, frequent dripper clogging, and uneven irrigation as their main reasons for reverting to open pipe.

3.6.4 Irrigation Through Pipes

Irrigation through open pipes is common practice across the study villages. Farmers typically practice surface irrigation by leaving a pipe in a terraced field for a set duration, wetting the soil to a depth of about 10 cm; during periods of water shortage, they instead use pipe-spraying, which wets the soil to a shallower depth of about 5 cm.

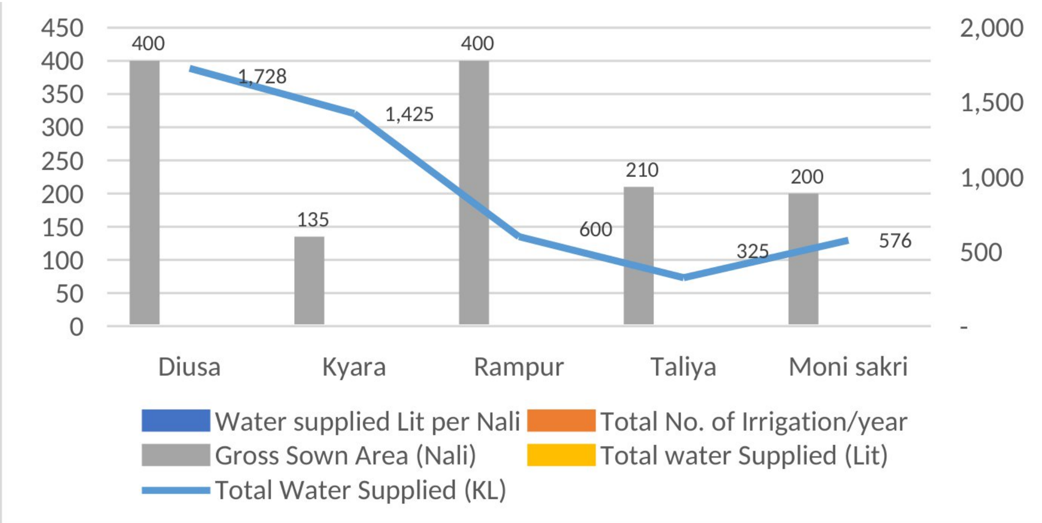
Table 3N — Village-Wise Irrigation Through Pipe

	Diusa	Kyara	Rampur	Taliya	Monisakri
Type of water	Gravity	Guhl + solar	Solar	Gravity	Solar

	Diusa	Kyara	Rampur	Taliya	Monisakri
scheme					
Water availability (L/day)	57,600	95,000	20,000	21,600	19,200
Water availability (L/month)	17,28,000	14,25,000	6,00,000	3,25,000	5,76,000
Water availability (L/Nali)	8,000	14,000	3,000	5,000	5,000

Water availability per Nali was highest in Kyara (14,000 L/Nali), where both gravity-fed and solar lift systems operate in tandem with 95 KL of storage capacity, giving an average monthly availability of 1,425 KL. Diusa followed at 1,728 KL a month from a 40 LPM source. Rampur's more limited storage capacity restricted monthly availability to 600 KL across 400 Nali of land; Taliya provided 325 KL a month across 210 Nali; and Monisakri, 576 KL a month across 200 Nali. Farmers reported that open-pipe irrigation is labour-intensive, that water loss to frequent pipe leaks is significant, and that shifting pipes between fields regularly damages standing crops.

Figure 3F — Support Irrigation through Pipes



A terraced vegetable plots. Part of a water distribution network.

3.6.5 Irrigation Through Sprinklers

In Saabli, a gravity-based irrigation scheme implemented in 2023-24 was paired with a sprinkler system: 1,600 sprinklers were distributed, averaging 10 per Nali (Table 3O, Table 3P).

Table 3O — Sprinkler System Specifications (Saabli)

Specification	Value
Length of HDPE distribution pipeline (m)	1,200
Distribution sub-line 1 (m)	150
Distribution sub-line 2 (m)	150
Distribution sub-line 3 (m)	200
No. of sprinklers	1,600
No. of sprinklers/Nali	10
Water supplied through sprinkler (L/day)	450

Table 3P — Water Distribution Through Sprinklers (Saabli)

Village	Water Available (L/Nali)	Irrigations/Year	Net Area Covered (Nali)	Total Water Availability (KL)
Saabli	4,500	5	300	6,750

Farmers report that sprinkler irrigation is beneficial during seed germination and early crop growth, but becomes difficult to use once the crop matures; the system also has to be dismantled after harvest and before land preparation for the next crop, which farmers find time-consuming and labour-intensive. The Saabli experience suggests that sprinkler layout needs to be adapted, and sprinkler types matched more carefully to mountain terrain, before wider adoption is encouraged.

3.7 Conclusion

This chapter has traced the complete water ecosystem across the study villages, surfacing a consistent set of gaps alongside clear evidence of what works. Detailed analysis and recommendations are consolidated in Chapter 6. The following conclusions summarize the data presented in this chapter.

Source Sustainability and Optimal Utilization

1. Identifying and treating the water source's catchment and recharge zone, and protecting the source, should be built into every irrigation project or scheme from the outset — not treated as an afterthought — and the support-irrigation system itself should be designed against a 20-year output horizon.
2. Most sources amenable to gravity-based schemes near settlements have already been developed for drinking water or irrigation. The remaining potential lies in sources beneath settlements and farmland, best reached through solar-powered lift irrigation; because petrol-driven pumps carry materially higher operating costs than solar, solar pumps of appropriately varied capacity should be the default, sized to local topography.
3. Lifting water from perennial streams and rivers via surface pump is generally the most suitable option where such sources exist, but proper operation and the safety of the pump against flash-flood risk must be assured through appropriate siting and storage design.
4. Where a water source's catchment falls within Reserved Forest, collaborative action with the Forest Department is required for geohydrological mapping, treatment, protection and management of the recharge zone. The Uttarakhand government's newly formed Spring and River Rejuvenation Authority (SARRA) is a natural partner for this work, and this study recommends active collaboration with SARRA to jointly identify recharge zones and plan their long-term treatment and maintenance.

Storage

1. Water storage tank capacity should be designed against measured water availability at source and the type of scheme (gravity, solar lift, etc.) to be constructed; in practice, storage decisions in several study villages were made on preliminary data rather than measured discharge, and there is a strong case for far greater rigor in DTR preparation on this point.
2. Villages situated in the uplands are mostly devoid of any nearby water source and remain entirely dependent on rainfed agriculture. Further action research is required on rainwater-harvesting options, storage capacity and distribution systems for critical crop irrigation in these locations. Farmers overall prefer a moderate-sized underground ferro-cement and/or RCC tank, though further piloting is needed to confirm the storage type best suited to mountain conditions and easy adoption.

Distribution

1. In the mountain region, farmers hold fragmented land in terraced fields. This topography calls for a decentralized water storage tank paired with an individual-level irrigation system, with the main tank connected to designated distribution tanks so that individual farmers can irrigate as needed, matched to field suitability and crop requirement.
2. Farmers have limited awareness of the optimum use of water for crop production and remain largely comfortable with flood irrigation. Water-use efficiency can be raised by promoting proper distribution systems and irrigation practice matched to actual crop requirement; an estimated 20–40% of wa-

ter is presently lost to transmission, and optimizing water use should become a key area of focus going forward.

3. Sprinkler irrigation is useful during germination and early crop growth but difficult to sustain once the crop matures, and the need to dismantle the system after each harvest makes it labour-intensive; sprinkler layout and type need to be adapted for mountain terrain before wider promotion.
4. Farmers are well acquainted with, and positive about, drip irrigation in apple orchards, where the system — installed once at establishment — continues to operate with minimal intervention through the orchard's life, saving both water and labour. Farmers who tried drip on vegetable crops mostly abandoned it, owing to the burden of removing and reassembling the system with each crop rotation, frequent dripper clogging, and uneven irrigation.

Chapter 4: Cropping Pattern and Crop Production

Women harvesting vegetables on a terraced plot in one of the study villages.

4.1 Background

This chapter examines vegetable, spice, cereal and pulse cropping patterns and practices across the study villages, to understand the constraints farmers face and to recommend solutions that improve water utilization and raise productivity at lower production cost. Three lenses are applied throughout: yield and productivity; before-and-after comparison; and the cost of production, including scope for improvement on wildlife damage, soil health and moisture, and the dissemination of package-of-practice (PoP) knowledge.

Following the introduction of irrigation facilities, farmers in the study villages are gradually shifting toward cash-crop cultivation, though some villages continue to grow traditional crops because of additional constraints on cash-crop production. Cropping patterns across the study villages fall into three broad categories: intercropping of orchards with vegetables; vegetable and spice cultivation; and cultivation of cereals and pulses.

4.2 Intercropping: Apple Orchards with Vegetables

In temperate parts of the study area, there is a discernible trend toward establishing temperate fruit orchards alongside vegetable cultivation. Two villages illustrate this trend: in Pujargaon, a high-density apple orchard was established with Himmotthan's support, while in Chopriyalgaon, a comparable orchard was established in 2021-22 under the state government's Apple Mission programme.

Table 4A — Agricultural Land Characteristics

	Chopriyalgaon	Pujargaon
Altitude (masl)	2,000	1,716
Aspect	SE-facing	SW-facing
Total households	13	3
Total land, Ha (Nali)	60	100
Area under irrigation, Ha (Nali)	0.52 (26)	0.42 (21)
No. of terraced fields	25	6
Land parcel	Consolidated	Fragmented
Soil type	Loamy soil	Loamy soil
Soil depth	~1.5–2 feet	~2 feet

4.2.1 High-Density Apple Orchard: Growth and Performance

In Pujargaon, the apple orchard was established in 2022-23 on 21 Nali of land by 13 members of the Shahid Nagendra Dutt Saklani self-help group, working collectively with technical support from Himmotthan. Planting followed protocols recommended by Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, and ICAR-CITH, Srinagar (J&K). Field observation of the orchard's performance points to a well-executed establishment: proper design and layout to technical guidelines; quality planting material sourced from a recognized Himachal Pradesh nursery; plantation carried out to standard operating procedure; a properly laid-out drip irrigation system, timed to soil-moisture status; timely fertigation and spraying under expert guidance; and regular protection through hail netting and chain fencing. Nine of the thirteen self-help group members remain active in the group's ongoing farming. Plant survival stands at 98%, and fruiting began in the third year.

Table 4B — Pujargaon Apple Orchard: Plant Growth and Spacing

Field No.	Highest Stem Dia. (in)	Lowest Stem Dia. (in)	Plant Height (ft)	Avg. Spacing (ft)	Avg. Branches/Plant
1	6.5	5.5	9.8	12.5	38
2	6.5	4.8	9.5	12.8	32
3	4.5	3.8	8.5	13.8	22
4	6.0	5.2	9.0	13.0	28
5–6 (avg.)	5.4	4.5	8.5	12.6	26
Overall average	5.6	4.7	8.9	—	28.5

Note: measurements were recorded for the high-density apple plantation (HDP) under field evaluation; stem diameter is trunk girth measured 15 cm above the graft union, and average spacing indicates plant-to-plant distance within the same planting line.

In Chopriyalgaon, progressive farmer Mr Khushi Ram Dabral established an orchard at Chunnipani hamlet on 26 Nali of land with technical support from the state Horticulture Department, planting 500 plants with a drip irrigation system but no hail-net protection. Field observation here tells a different story: poor design and layout — the planting could have been accommodated on 11 Nali rather than 26; poor-quality planting material, with plants small and weak at the time of planting; inadequate farmyard manure and fertilizer at planting; an unevenly performing drip system; insufficient irrigation water during the critical period; limited transfer of knowledge and technology from the implementing organization; and inadequate post-planting maintenance, with the farmer left to self-fund O&M. Of 500 plants, 120 have died — a 76% survival rate — and while some plants have reached fruiting stage, fruit size remains small. The farmer intends either to replace the orchard with better planting material or with alternative fruit species, and is meanwhile sustaining farm income through vegetable intercropping.

Table 4C — Chopriyalgaon Apple Orchard: Plant Growth and Spacing

Field No.	Highest Stem Dia. (in)	Lowest Stem Dia. (in)	Plant Height (ft)	Avg. Spacing (ft)	Avg. Branches/Plant
1	2.9	2.1	4.8	13.5	8
2	3.2	2.4	4.9	14.5	10
3	4.4	3.6	8.2	14.8	22
4	3.5	2.6	6.1	15.0	13
5	4.2	3.5	6.5	12.5	24
6	4.5	3.5	8.1	13.2	18
Overall average	3.8	2.9	6.4	—	15.8

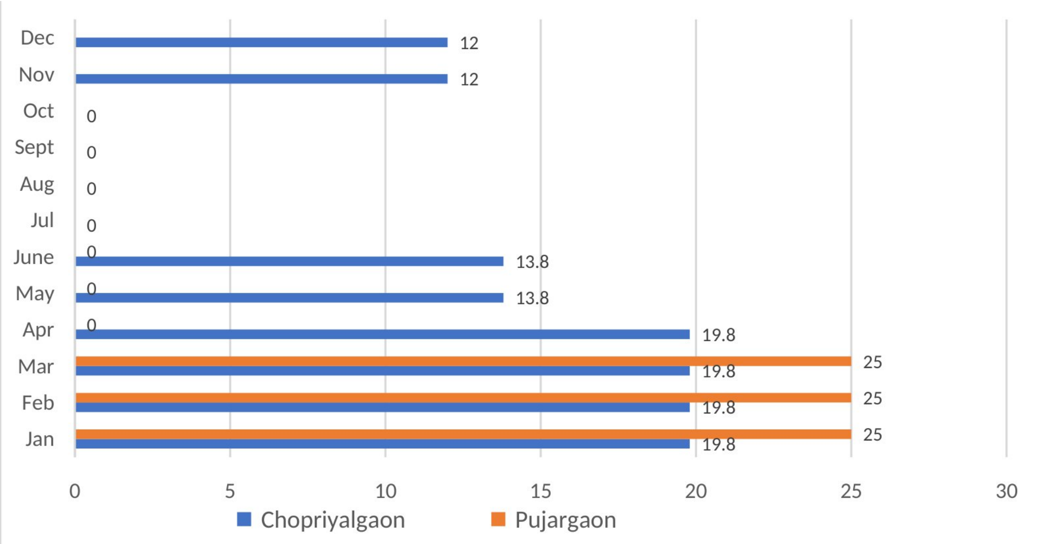
Set side by side, the two orchards make a clean natural experiment in what execution quality is worth: Pujargaon's average plant height of 8.9 feet, stem diameter of 5.2 inches and 28.5 branches per plant compare with Chopriyalgaon's 6.4 feet, 3.4 inches and 15.8 branches — roughly half the vegetative growth, from an orchard planted at a similar time with more than double the density of plants per unit area.

A high-density apple orchard with hail-protection netting, established by a women's self-help group with drip irrigation.

4.2.2 Seasonality of Irrigation: Intercropping

In Chopriyalgaon, around 130 KL of water is available annually for supplementary irrigation, used across eight months to grow vegetables and spices; irrigation is concentrated on Rabi crops (vegetable pea, garlic, leafy vegetables) from December to April, with critical irrigation for Kharif vegetables required in May and June, and Jaid-season irrigation directed mainly at the vegetable pea crop.

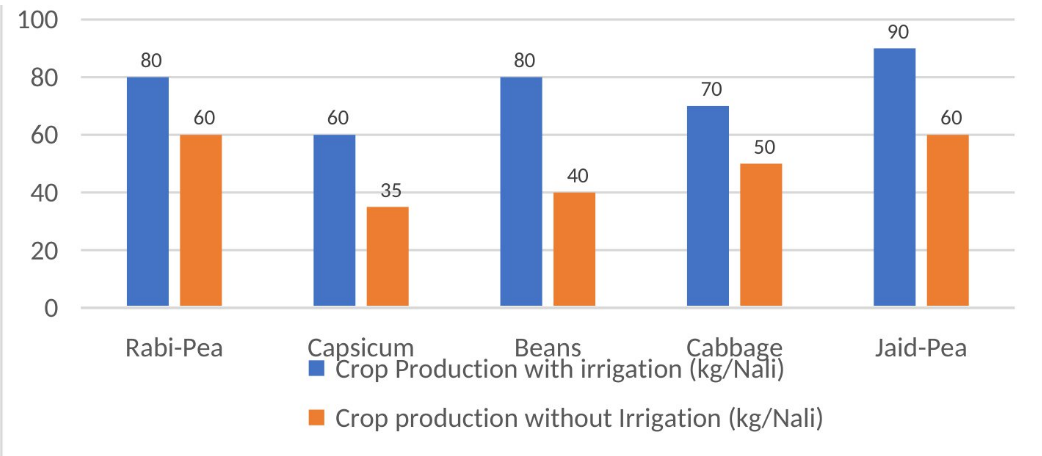
Figure 4A — Seasonality of Irrigation (KL/Month): Intercropping



4.2.3 Crop Production: Yield and Income

Both villages sit in the temperate zone and traditionally grew vegetables under rainfed conditions; the availability of critical irrigation has lifted production substantially, and has also allowed farmers to sow 15–20 days earlier, so that crops mature 15–20 days sooner and reach market ahead of the seasonal glut, commanding a premium price. Comparing production with and without irrigation: Rabi-season vegetable pea rose from 60 to 80 kg/Nali; Jaid-season vegetable pea, from 60 to 90 kg/Nali; capsicum, from 35 to 60 kg/Nali; beans roughly doubled, from 40 to 80 kg/Nali; and cabbage rose from 50 to 70 kg/Nali.

Figure 4B — Crop Production: With and Without Irrigation



In Chopriyalgaon, farmers cultivate vegetables across 130 Nali of gross sown area, producing 11,380 kg annually and earning around Rs. 8,39,300 a year from vegetable sales — Rs. 2,79,770 per household. In Pujargaon, farmers now grow only the winter pea crop beneath the orchard, earning Rs. 1.8 lakh a year (Table 4D).

Table 4D — Vegetable Production and Income

	Gross Sown Area (Nali)	Total Production (kg)	Total Income (Rs.)
Chopriyalgaon — Rabi vegetables	35	2,790	2,48,600
Chopriyalgaon — Kharif vegetables	35	3,040	2,17,200
Chopriyalgaon — Jaid vegetables	60	5,550	3,73,500

	Gross Sown Area (Nali)	Total Production (kg)	Total Income (Rs.)
Chopriyalgaon — Total	130	11,380	8,39,300
Chopriyalgaon — Per household	—	—	2,79,767
Pujargaon — Rabi vegetable pea	20	1,800	1,80,000

4.2.4 Before-and-After Production and Income

Table 4E — Chopriyalgaon: Crop Production and Income, With and Without Irrigation

		Gross Sown Area (Nali)	Total Production (kg)	Total Income (Rs.)
With irrigation	Rabi vegetables	35	2,790	2,48,600
With irrigation	Kharif vegetables	35	3,040	2,17,200
With irrigation	Jaid vegetables	60	5,550	3,73,500
With irrigation	Total / Per HH	130	11,380	8,39,300 / 2,79,767
Without irrigation	Rabi vegetables	28	1,640	1,43,000
Without irrigation	Kharif vegetables	30	2,165	1,41,800
Without irrigation	Jaid vegetables	50	3,450	1,74,750
Without irrigation	Fallow land	22	0	—
Without irrigation	Total / Per HH	130	7,255	4,59,550 / 1,53,183

4.2.5 Fruit Production from the Orchard

Fruit production in the apple orchards began in the third year and is expected to peak from the eighth year onward. In Pujargaon, fruit production is estimated to reach 286 quintals annually at maturity (Table 4F).

Table 4F — Investment in Orchard and Production

	Pujargaon	Chopriyalgaon
No. of farmers	13	3
Total area (Nali)	20	26
Total plants (No.)	1,300	500
Total establishment cost (Rs. lakh)	18.96	8.20
Annual maintenance (Rs.)	10,000	10,000
Fruit production, Year 3 (Qtl)	52	15
Total market value (Rs.)	5,20,000	1,50,000
Sale of vegetables (Rs.)	1,80,000	8,39,300
Total annual income (Rs.)	7,00,000	9,89,300
Per household income (Rs.)	77,778	3,29,767

- Pujargaon: per-Nali establishment cost of Rs. 94,820 and per-plant cost of Rs. 1,459; a fragmented-land intervention delivered through group farming, showing a year-on-year rise in income as fruit production increases, and well suited to Rabi-season vegetable cultivation.
- Chopriyalgaon: intercropping vegetables with the orchard remains the major source of farm income while the orchard itself continues to underperform.

4.3 Vegetable and Spice Cultivation: Yield and Income

With irrigation facilities in place, farmers have begun cultivating off-season vegetables and spices. Four villages that intensively cultivate vegetables and spices were studied (Table 4G).

Table 4G — Agricultural Land Characteristics

	Diusa	Kyara	Monisakri	Taliya
Altitude (masl)	1,200	1,400	1,300	1,300
Aspect	SW-facing	SW-facing	SW-facing	SW-facing
Total households	26	5	13	15
Total land, Ha (Nali)	6 (300)	247 (12,340)	4 (200)	4.56 (228)
Total irrigated land, Ha (Nali)	4 (200)	60	100	1.5 (75)
No. of terraced fields	75	40	60	40
Land parcel	Fragmented	Consolidated	Fragmented	Fragmented
Soil type	Sandy loam	Sandy loam	Loamy soil	Loamy soil
Soil depth (ft)	~2	~2	~1.5–2	~2

A terraced vegetable plot under supplementary irrigation, in one of the study's vegetable- and spice-growing villages.

4.3.1 Changes in Land-Use Pattern

Land-use data show a consistent rise in gross sown area following the installation of irrigation facilities across all four villages (Table 4H).

Table 4H — Change in Land-Use Pattern (Area in Nali)

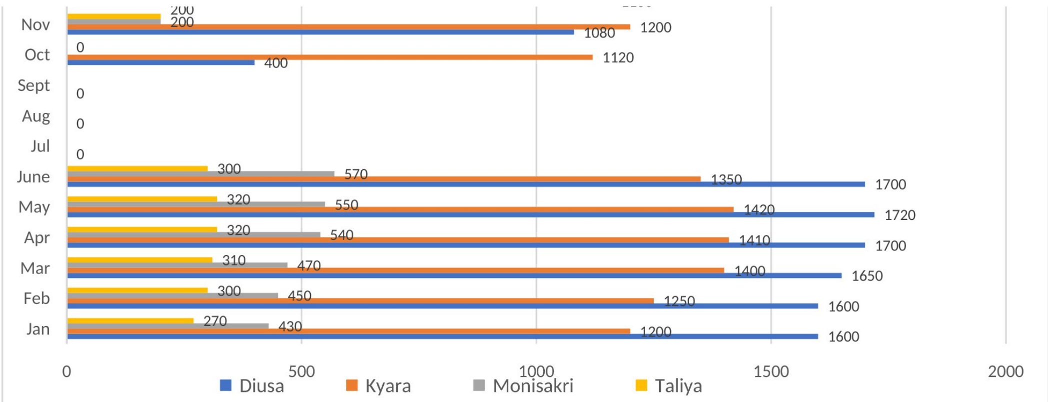
Land Use	Diusa (Before)	Diusa (After)	Kyara (Before)	Kyara (After)	Mon-isakri (Before)	Monisakri (After)	Taliya (Before)	Taliya (After)
Rabi vegetables	0	115	10	35	35	80	15	55
Rabi spices	0	85	0	2	25	20	10	20
Rabi cereals	0	0	10	5	30	0	40	0
Rabi pulses	0	0	0	0	10	0	10	0
Kharif vegetables	0	145	25	41	30	85	20	65
Kharif pulses	0	0	0	0	15	0	0	0
Kharif spices	0	50	15	12	20	10	25	10
Kharif cereals	0	0	0	0	30	0	30	0
Jaid vegetables	0	5	25	40	5	5	40	60
Fallow land	200	0	10	0	100	100	0	0
Total	200	400	95	135	300	300	190	210

In Diusa, the entire 200-Nali parcel was barren before intervention; following the creation of irrigation facilities by Himmotthan and installation of chain-link fencing by the block office, the whole parcel is now under vegetable and spice cultivation. In Kyara, gross sown area rose from 95 Nali (including 10 Nali fallow) to 135 Nali. In Monisakri, cereal and pulse cultivation has largely given way to vegetables and spices on 100 Nali of land. In Taliya, the area formerly under cereals and pulses has converted entirely to vegetables and spices.

4.3.2 Seasonality of Irrigation: Vegetables and Spices

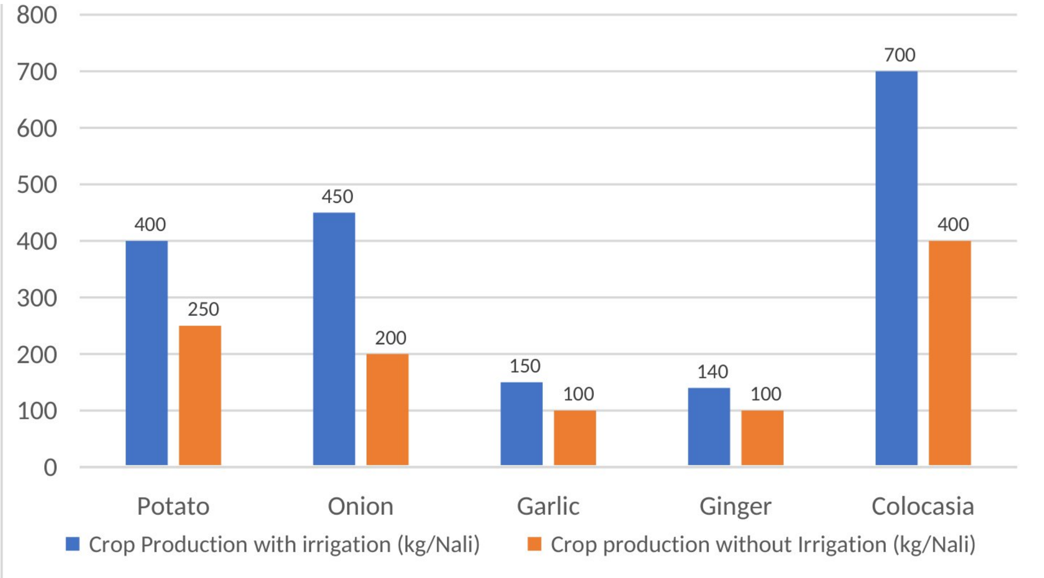
Farmers in Diusa and Kyara irrigate for nine months of the year, reflecting the lower moisture-holding capacity of their sandy loam soils; in Monisakri and Taliya, loamy soils with better moisture retention allow farmers to irrigate for eight months. On an annual basis, Diusa uses roughly 12,610 KL of water for vegetable irrigation, concentrated in winter and summer; Kyara uses about 11,650 KL; Monisakri, about 3,610 KL; and Taliya, about 2,270 KL.

Figure 4C — Seasonality of Irrigation (KL/Month): Vegetables and Spices



Across these villages, potato production rose from 250 to 400 kg/Nali with irrigation; colocasia, from 400 to 700 kg/Nali; and onion roughly doubled, from 200 to 450 kg/Nali. Among spices, garlic rose from 100 to 150 kg/Nali and ginger from 100 to 140 kg/Nali.

Figure 4D — Crop Production: With and Without Irrigation



4.3.3 Vegetables and Spices: Yield and Income Before Intervention

With the exception of Kyara, the remaining study villages (Monisakri, Taliya) cultivated cereals and mixed crops before irrigation intervention; in Diusa, the land was fallow prior to intervention (Table 4I).

Table 4I — Crop Yield and Income Before Intervention

	Kyara: Area (Nali)	Kyara: Prodn (kg)	Kyara: Income (Rs.)	Monisakri: Area (Nali)	Mon-isakri: Prodn (kg)	Monisakri: Income (Rs.)	Taliya: Area (Nali)	Taliya: Prodn (kg)	Taliya: Income (Rs.)
Rabi vegetables	10	700	49,000	35	6,050	1,21,000	15	2,650	53,000
Rabi spices	0	0	—	25	1,600	82,000	10	550	28,500
Rabi cereals	10	560	12,376	30	1,150	19,650	40	1,650	28,350
Rabi pulses	0	0	—	10	150	11,250	10	200	14,000
Kharif vegeta-bles	25	7,020	1,17,600	30	7,350	1,70,500	20	2,400	40,000
Kharif pulses	0	0	—	15	375	30,000	0	0	—
Kharif spices	15	2,250	1,46,250	20	1,800	1,28,000	25	2,300	1,46,000
Kharif cereals	0	0	—	30	950	22,000	30	1,800	51,750
Jaid vegetables	25	2,250	1,46,250	5	1,500	22,500	40	2,600	1,30,000
Total	85	—	4,71,476	200	—	6,06,900	190	—	4,91,600
Per household	—	—	94,295	—	—	46,685	—	—	32,773

Note: in Diusa, the land parcel was barren before intervention. Even before intervention, per-household income was highest in Kyara, followed by Monisakri and Taliya — though household-level figures were modest across all three.

4.3.4 Vegetables and Spices: Yield and Income After Intervention

Table 4J — Vegetables and Spices Production: Yield and Income After Intervention

	Diusa: Area	Diusa: Prodn (kg)	Diusa: Income (Rs.)	Kyara: Area	Kyara: Prodn (kg)	Kyara: Income (Rs.)	Monisakri: Area	Monisakri: Prodn (kg)	Monisakri: Income (Rs.)	Taliya: Area	Taliya: Prodn (kg)	Taliya: Income (Rs.)
Rabi vegetables	115	36,250	9,12,500	35	5,000	3,60,000	80	22,550	7,39,000	55	16,350	5,22,500
Rabi spices	85	25,250	10,25,000	2	40	4,800	20	2,350	2,37,000	20	3,000	3,00,000
Kharif vegetables	145	30,800	10,27,000	41	15,870	2,81,000	85	33,450	10,23,000	65	18,350	5,46,500
Kharif spices	50	8,750	8,25,000	12	2,400	2,40,000	10	2,000	1,80,000	10	1,400	98,000
Jaid vegetables	5	2,500	1,00,000	40	4,000	4,00,000	5	2,000	50,000	60	6,000	5,40,000
Total	—	—	38,89,500	135	—	12,97,160	200	—	22,29,000	210	—	20,07,000
Per household	—	—	1,49,596	—	—	2,59,432	—	—	1,71,462	—	—	1,33,800

Per household, farm income after intervention was highest in Kyara, followed by Diusa, Monisakri and Taliya — a 5- to 10-fold rise in income across the study villages compared with pre-intervention levels.

4.4 Cereals and Pulses Mixed Cropping: Yield and Income

Three study villages — Rampur, Saabli and Simoldi — remain engaged in cereal-dominated mixed cropping. In these villages, average per-household landholding is only about 5 Nali and highly fragmented (Table 4K).

Table 4K — Agricultural Land Characteristics

	Rampur	Saabli	Simoldi
Altitude (masl)	900	1,250	1,100
Aspect	SW-facing	NE-facing	SW-facing
Total households	42	32	20
Total land, Ha (Nali)	5 (250)	12 (600)	4.4 (220)
Total irrigated land, Ha (Nali)	4 (200)	3 (150)	2 (100)
No. of terraced fields	60	70	40
Land parcel	Fragmented	Fragmented	Fragmented
Soil type	Sandy loam	Sandy loam	Sandy loam
Soil depth (ft)	~2	~2	~2

4.4.1 Changes in Land-Use Pattern

Unlike the vegetable-dominant villages, gross crop sown area in Rampur, Saabli and Simoldi did not rise substantially after irrigation facilities became available. The area under vegetables and spices increased in all three, but without a corresponding fall in the area under cereals and pulses — farmers instead cultivate vegetables collectively on small patches within an otherwise unchanged cropping footprint (Table 4L).

Table 4L — Changes in Land-Use Pattern (Area in Nali)

Land Use	Rampur (Before)	Rampur (After)	Saabli (Before)	Saabli (After)	Simoldi (Before)	Simoldi (After)
Rabi vegetables	15	30	15	51.5	30	40
Rabi spices	10	25	10	19.6	10	15
Rabi cereals	125	105	95	63	60	45
Rabi pulses	50	40	20	15.9	0	0
Kharif vegetables	40	64	20	60	0	0
Kharif pulses	60	31	15	10	10	10
Kharif spices	20	25	14	30	0	0
Kharif cereals	80	80	96	45	90	90
Jaid vegetables	0	0	5	5	10	30
Fallow land	0	0	10	0	0	0
Total	400	400	300	300	210	230

4.4.2 Seasonality of Irrigation: Cereals and Pulses Mixed Cropping

Farmers in Simoldi, Saabli and Rampur irrigate for around nine months of the year. In June–July, water is used to transplant paddy; in the Rabi season, irrigation goes to cereals and pulses (wheat, barley, lentils) and to onion, garlic, turmeric and leafy vegetables; in Kharif, to capsicum and cabbage, as well as paddy and millet. Before irrigation, farmers cultivated rainfed paddy directly; after intervention, they transplant paddy seedlings, and in Rampur, millet seedlings are transplanted as well. Wheat production doubled from 40 to 80 kg/Nali; millet rose from 30 to 50 kg/Nali; paddy, from 90 to 120 kg/Nali; lentil, from 15 to 25 kg/Nali; and soybean, from 35 to 45 kg/Nali.

Figure 4E — Seasonality of Irrigation (KL/Month): Mixed Crops

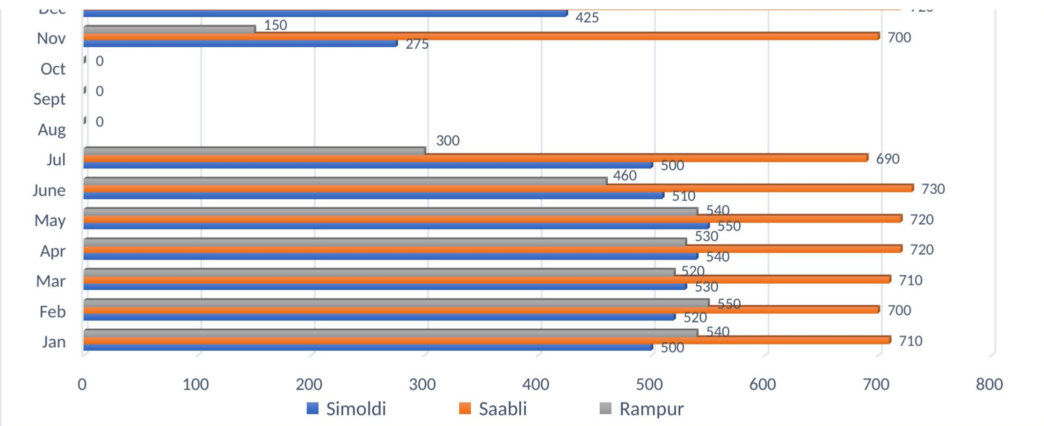
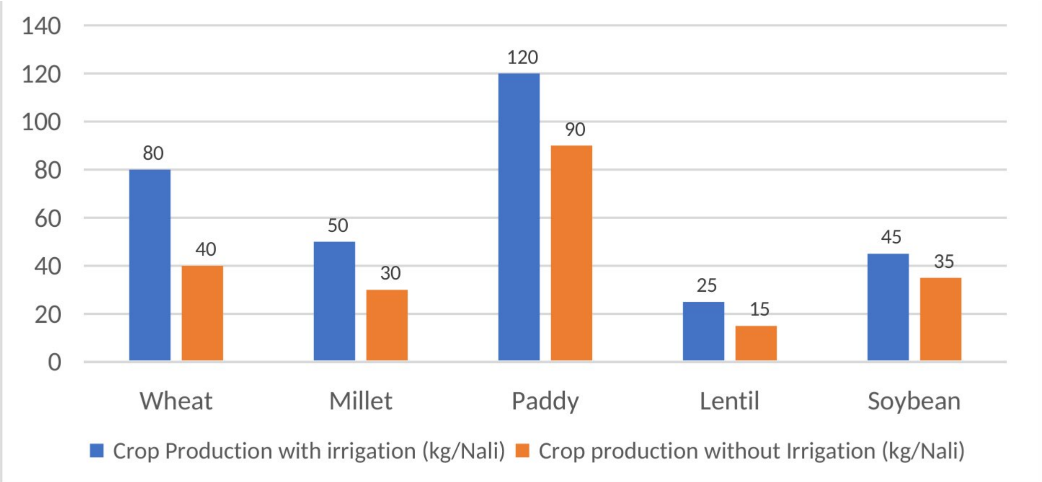


Figure 4F — Crop Production: With and Without Irrigation



4.4.3 Cereals and Pulses Mixed Crop Production: Yield and Income Before Intervention

Before intervention, farmers cultivated cereals, pulses and vegetables under rainfed conditions. Total annual production stood at 218 quintals from 400 Nali of gross sown area in Rampur, 151 quintals from 290 Nali in Saabli, and 171 quintals from 210 Nali in Simoldi (Table 4M).

Table 4M — Cereals and Pulses Mixed Crop Production: Yield and Income Before Intervention

	Rampur: Area	Rampur: Prodn (kg)	Rampur: Income (Rs.)	Saabli: Area	Saabli: Prodn (kg)	Saabli: Income (Rs.)	Simoldi: Area	Simoldi: Prodn (kg)	Simoldi: Income (Rs.)
Rabi vegetables	15	2,400	43,000	15	2,575	46,500	30	6,300	1,20,250
Rabi spices	10	550	28,500	10	575	30,250	10	700	28,500
Rabi cereals	125	4,925	87,075	95	3,325	58,275	60	2,400	43,200
Rabi pulses	50	875	63,125	20	350	28,250	0	0	—
Kharif vegetables	40	5,160	1,00,800	20	1,900	50,000	0	0	—
Kharif pulses	60	1,900	1,02,000	15	450	45,000	10	300	16,500
Kharif spices	20	1,800	1,16,000	14	1,240	80,800	0	0	—
Kharif cereals	80	4,200	1,18,500	96	3,950	1,02,350	90	6,300	1,84,500
Jaid vegetables	0	0	—	5	750	22,500	10	1,100	27,500
Total	400	—	6,59,000	290	—	4,63,925	210	—	4,20,450
Per household	—	—	15,690	—	—	14,498	—	—	21,023

4.4.4 Cereals and Pulses Mixed Crop Production: Yield and Income After Intervention

With irrigation facilities available, crop production rose substantially: to 589 quintals from 400 Nali in Rampur, 498 quintals from 300 Nali in Saabli, and 386 quintals from 230 Nali in Simoldi (Table 4N).

Table 4N — Cereals and Pulses Mixed Crop Production: Yield and Income After Intervention

	Rampur: Area	Rampur: Prodn (kg)	Rampur: Income (Rs.)	Saabli: Area	Saabli: Prodn (kg)	Saabli: Income (Rs.)	Simoldi: Area	Simoldi: Prodn (kg)	Simoldi: Income (Rs.)
Rabi vegetables	30	8,500	2,35,000	51.5	18,390	4,61,700	40	14,300	4,35,000
Rabi spices	25	2,450	2,51,000	19.6	1,692	1,73,040	15	1,600	1,62,000
Rabi cereals	105	8,400	2,60,000	63	5,040	1,54,000	45	3,600	1,08,000

	Rampur: Area	Rampur: Prodn (kg)	Rampur: Income (Rs.)	Saabli: Area	Saabli: Prodn (kg)	Saabli: Income (Rs.)	Simoldi: Area	Simoldi: Prodn (kg)	Simoldi: Income (Rs.)
Rabi pulses	40	1,000	1,10,000	15.9	397.5	41,350	0	0	—
Kharif vegetables	64	25,340	9,08,200	60	14,175	4,08,300	0	0	—
Kharif pulses	31	1,220	2,16,400	10	400	60,000	10	500	75,000
Kharif spices	25	4,500	4,35,000	30	5,250	4,72,500	0	0	—
Kharif cereals	80	7,500	3,42,000	45	1,975	98,250	90	8,700	3,96,000
Jaid vegetables	0	0	—	5	2,500	87,500	30	9,900	3,96,000
Total	400	—	27,57,600	300	—	19,56,640	230	—	15,72,000
Per household	—	—	65,657	—	—	61,145	—	—	78,600

4.5 Crop Production in an Unirrigated Rainfed Village

Nald village in Bhatwari block, Uttarkashi, was chosen as a rainfed comparison case against the irrigated study villages. Farmers here practice entirely rainfed agriculture; average family landholding is 5 Nali and highly fragmented (Table 4O).

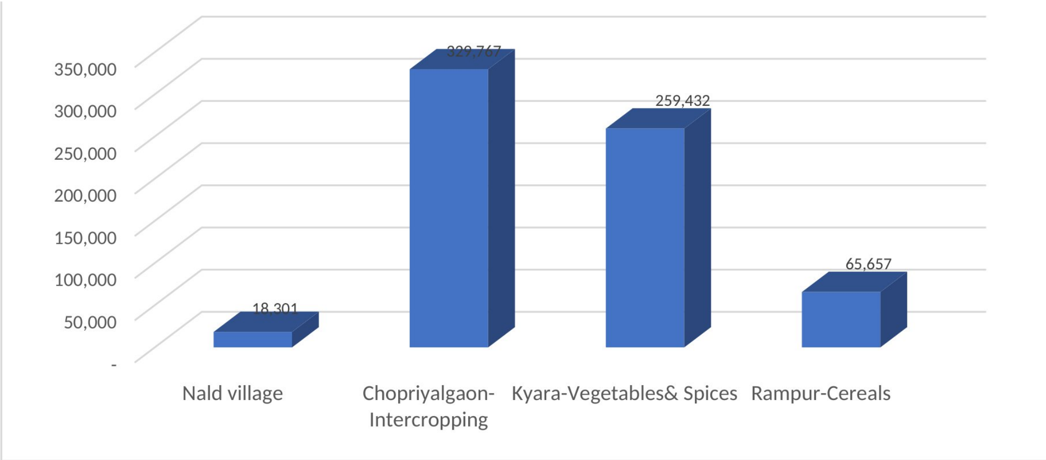
Table 4O — Agricultural Land Characteristics (Nald)

	Value
Altitude (masl)	1,200
Aspect	SE-facing
Total households	163
Total agricultural land (Nali)	750
Cultivable wasteland (Nali)	150
Net sown area (Nali)	600
Land holding	Fragmented
Soil type	Loamy
Soil depth	~2 feet

Agricultural land in Nald is divided into two parcels — Pilona and Tard — between which Rabi and Kharif crops alternate. Alongside cereals and pulses, farmers also grow potato, pea, garlic and colocasia for sale, though most cereal production is retained for self-consumption. Most households still plough with bullocks, and compost application and crop mulching for soil-moisture conservation remain in active practice. Women are the primary agricultural workforce; men's involvement is mainly confined to ploughing and harvest. A rapid rise in crop damage by wildlife has, in turn, driven an increase in the area of cultivable land left fallow. Given limited and unreliable farm income, households have diversified into livestock products, seasonal labour and tourist-season work at hotels and roadside dhabas.

Per-household annual income from crop production in unirrigated Nald was recorded at just Rs. 18,300 — markedly lower than every irrigated study village. By comparison, the highest household annual income recorded across the study, Rs. 3,29,770, was in Chopriyalgaon, where orchards are intercropped with vegetables; Kyara followed at Rs. 2,59,432 (vegetables and spices), and Rampur, the cereal-dominated mixed-cropping village, recorded Rs. 65,657. Ms. Shakuntala Devi, a Nald resident, put the underlying calculus starkly: “We are cultivating the fields only because we live here and don't want to keep our land fallow; there is no reward for our hard work.” The roughly eighteen-fold income gap between Nald and Chopriyalgaon is, in the study team's assessment, the single clearest quantitative demonstration in this report of what reliable water access is worth to a mountain household.

Figure 4G — Per Household Annual Income (Rs.)



4.6 Other Limiting Factors in Crop Production

Fragmented Land Holdings

In most of the older-settlement villages — Saabli, Simoldi, Rampur among them — land is highly fragmented, with average household holdings of roughly 5 Nali split across frequent intra-family division. Production decisions in these villages depend on the collective judgement of many small households at once, making the transition from traditional to cash-crop cultivation harder for any single family to undertake alone.

Damage by Wild Animals

Crop damage from wildlife is a significant constraint in every study village. In Rampur, Saabli and Simoldi, farmers cite wildlife damage as the main reason they have not converted to cash-crop cultivation; in rainfed Nald, farmers have abandoned distant fields altogether because of repeated wildlife incursion. Diusa offers a working counter-example: land that was entirely barren before intervention has been brought into cash-crop cultivation, made possible by pairing irrigation with chain-link fencing. Cash-crop cultivation without adequate fencing is, in practice, not viable; chain-link fencing topped with solar fencing should be considered as integral to irrigation facilities as the irrigation infrastructure itself.

Limited Dissemination of Knowledge

In most villages, farmers are unaware of the recommended package of practices (PoP) for cultivating high-yielding cash crops. Fertilizer and pesticide use in vegetable cultivation is rising steadily, in the absence of proper knowledge of integrated pest and nutrient management (IPNM); it can reasonably be assumed that production costs are correspondingly high and rising because of excessive input use. Timely dissemination of technical knowledge to farmers is essential, and reducing production cost while safeguarding the long-run viability of agriculture in the region should be a future area of study.

Soil Health and Soil Moisture

Although most mountain areas of Uttarakhand are nominally organic by default, compost production and field application have gradually declined over the years. Maintaining soil health and soil moisture to optimize crop production should be treated as a distinct area of future focus.

4.7 Cost of Production

Crop production in Uttarakhand's mountain areas is organic by default, but in villages where farmers grow vegetables and spices commercially, production costs are rising markedly, driven by greater reliance on external suppliers for seed, fertilizer and insecticide. Where farmers are replacing traditional cereal and pulse cultivation with vegetable crops, they are also gradually shifting from organic to inorganic production, using fertilizer and pesticide to raise yield.

Table 4P — Annual Crop Production Cost, Kyara Village

Particular	Total Annual Expenditure (Rs.)
Seed purchase and treatment	7,800
Fertilizers	20,000
Insecticides / pesticides / fungicides	5,200
Crop maintenance (irrigation, protection, etc.)	2,000
Extra labour (land preparation, harvesting, etc.)	10,000
Total	45,000

Note: family labour cost is not included in the annual crop production cost above.

- Farmers are extensively purchasing vegetable seed — pea, potato, cabbage, capsicum, beans and others — from outside markets.
- Organic manure application is declining as livestock numbers and composting practice decline.
- Farmers are increasing fertilizer and pesticide use to raise vegetable yields, with dosages rising year on year in the absence of proper package-of-practice knowledge.
- Farmers must also invest in crop protection — chiefly against wildlife and stray animals — and in maintaining irrigation facilities.
- Production cost is further rising as the use of bullocks and machinery for land preparation declines, and as harvesting, post-harvest handling and marketing costs increase.

Climate-linked risk compounds these cost pressures: hailstorms and untimely rain periodically inflict heavy crop losses, against which farmers presently have only limited support from government or external agencies.

4.8 Conclusion

1. In high-altitude temperate areas, vegetable cultivation offers farmers a better income option than traditional cereal and pulse cultivation. Given constraints on production such as a shrinking workforce and limited resources, farmers should be encouraged to intercrop temperate orchards with off-season vegetables to reduce input cost and raise profit margins.
2. Compared with rainfed conditions, irrigation availability raises crop production by roughly 1.5 to 2 times. Irrigation substantially increases crop yield and, with it, farmer income; however, other constraints — wildlife damage, cluster-based bulk production requirements and limited marketing facilities — continue to discourage farmers from adopting cash-crop cultivation, and should be addressed alongside irrigation itself to maximize output.
3. Area under cash-crop production is greater in villages with consolidated landholdings than in villages with fragmented holdings. Where land is fragmented, farmers should be encouraged to practice ‘group farming’ to cultivate selected cash crops across the entire agricultural patch collectively.

4. Given the very small average landholding across Uttarakhand's hill villages, efforts should also focus on raising gross cropped area under production, by promoting short-duration, off-season vegetables and spices — coriander leaves and radish through the monsoon, pea and beans through the autumn.
5. In villages where farmers grow vegetables and spices commercially, production costs are rising significantly as farmers shift from organic to inorganic cultivation. There is an urgent need to introduce integrated productivity management (IPM) practice and materially improve extension services for farmers; unless production costs are brought under control, farmers risk incurring significant debt, and cumulative damage to soil health will follow.
6. Damage to standing crops by wildlife is substantial across the study villages and currently unquantified. Cash-crop cultivation without adequate fencing is not viable; chain-link fencing topped with solar fencing should be treated as integral to irrigation facilities, not an optional add-on.
7. Compost production and field application have declined gradually over the years. Maintaining soil health and soil moisture to optimize crop production should be established as a distinct area of ongoing focus.

Chapter 5: Investments, Institutions, Efficiency and Sustainability of Interventions

A Water User Committee meeting with village members during the field study.

5.1 Background

This chapter assesses the sustainability of the study interventions from two angles: financial and institutional. It examines the cost of investment in different types of structure and scheme in detail; most physical interventions studied are subsidized under one project or another, and there is a case for gradually reducing that subsidy wherever a scheme shows genuine potential for scale. It then examines the institutional arrangements through which communities manage these interventions — ownership at the community level, the O&M model for both hardware and continuous capacity-building, and the collection of community contributions toward O&M — along with governance structures, including mechanisms for resolving conflict. The chapter closes by drawing together many of the recommendations that emerge across the report, which the study team regards as fundamental to achieving genuine sustainability of intervention.

5.2 Investments, Sustainability — Institutional and Schemes, Returns

5.2.1 Investments

Most supplementary-irrigation interventions in the mountains are carried out by state government line departments or non-profit organizations under various programmes and schemes. Project proposals and the Detailed Technical Report (DTR) are generally prepared by external agencies, with limited involvement from the local community at this stage; community involvement typically begins only once implementation is under way, and community contribution is generally planned at around 10% of total cost.

Table 5A sets out investment in gravity-based irrigation schemes for agricultural production in four villages; Table 5B, gravity-based schemes paired with orchard development in two villages; Table 5C, solar-based lift irrigation schemes for agriculture in four villages; and Table 5D, petrol-based water pumps in two villages.

Table 5A — Gravity-Based Irrigation Schemes for Agricultural Production

Village	Total Investment (Rs.)	Community Contribution (Rs.)	Implementing Agency	Key Interventions
Diusa	2,83,060	28,306	Himmotthan-Sus+	Source work, chamber, LDPE tank, HDPE line
Kyara	1,84,240	18,500	Himmotthan-Sus+	Distribution network — HDPE pipeline
Saabli	5,20,000	18,500	Himmotthan-Titan	Source work, RCC tank, HDPE line, sprinklers
Taliya	2,72,917	27,292	Himmotthan-ABF	Source work, chamber, LDPE tank, HDPE line

Table 5B — Gravity-Based Irrigation Scheme plus Orchard Development

Village	Total Investment (Rs.)	Community Contribution (Rs.)	Implementing Agency	Key Interventions
Chopriyalgaon	6,50,000	1,20,000	Horticulture Dept.	LDPE tank, HDAO with drip irrigation
Pujargaon	19,06,400	1,90,640	Himmotthan-JICA	Syntax tank, HDPE pipe, HDAO with drips

Table 5C — Solar Lift Irrigation Scheme for Agricultural Production

Village	Total Investment (Rs.)	Community Contribution (Rs.)	Implementing Agency	Key Interventions
Kyara-Badait	16,00,000	1,60,000	UREDA	25 KL RCC tank, 5 kW solar lift surface pump
Rampur	3,45,476	34,548	Himmotthan-Sus+	Source tank, 5 kW solar lift submersible pump, HDPE pipe
Monisakri	3,62,926	36,293	Himmotthan-Sus+	Source, storage tank, 5 kW solar lift submersible pump, HDPE pipe
Simoldi	5,66,698	56,670	Himmotthan-Sus+	20 KL geomembrane tank, 5 kW solar lift surface pump

Table 5D — Petrol-Driven Water Pump

Village	Total Investment (Rs.)	Community Contribution (Rs.)	Implementing Agency	Key Interventions
Silla	32,000	3,200	Himmotthan-ABF	5.5 HP / 3.6 kW petrol-driven lift pump
Rampur	32,000	6,400	Agriculture Dept.	5.5 HP / 3.6 kW

Village	Total Investment (Rs.)	Community Contribution (Rs.)	Implementing Agency	Key Interventions
				petrol-driven lift pump

- Investment in gravity-based support irrigation goes mainly toward work at the source (diversion chamber, source protection work), the diversion Guhl or pipeline (HDPE pipe), storage tanks and the distribution pipeline. Across the study villages, the average cost of installing a gravity-based irrigation scheme is around Rs. 3.15 lakh per scheme, with a 10% community contribution.
- Investment in supplementary irrigation for high-density orchards additionally covers storage tanks, pipelines for water collection and distribution, and establishment of the drip system. In Pujargaon, total investment of Rs. 19 lakhs established a high-density orchard on 20 Nali of land, at an average cost of Rs. 1,500 per plant, inclusive of planning materials, planting and the drip system.
- The average cost of establishing a 5-kW solar-powered lift irrigation system across the study villages was around Rs. 7.18 lakh, covering source work, storage tank at source, solar panels, the lift pump itself, and the water storage and distribution system.
- Himmotthan has provided 5 HP petrol-driven water pumps to farmers on a pilot basis; the state government line department also supplies petrol-driven pumps to farmers at a subsidized cost.

Overall, interventions promoting support irrigation are being delivered almost entirely with external funding, leaving rural communities with a limited financial stake: in Himmotthan-implemented villages the programme funded roughly 90% of cost against a 10% community contribution, and even state-implemented schemes carry substantial subsidy. Farmers in the study villages consistently reported that, having seen the effect of irrigation on crop production, they are now more inclined to contribute toward such interventions themselves. There is accordingly a case for gradually raising the community contribution at the point of intervention, both to strengthen accountability and to build the ownership that long-run sustainability depends on.

5.3 Institutional Sustainability: O&M Arrangement for Scheme Management

Institutional sustainability is as critical to a scheme's survival as the hardware itself, and depends on genuine community ownership: governance structures and mechanisms, together with regular collection of funds for O&M. Each scheme's status is assessed here across three dimensions: status of the Water User Group (WUG); regularity of O&M collection; and governance structure.

In most study villages, a Water User Committee has been formed to operate and manage supplementary irrigation on fragmented landholdings. The WUG is typically formed during the planning phase, with all stakeholders involved, and plays a central role in the smooth installation of the intervention. In every village, the community has contributed roughly 10% of total investment, in cash or in kind; after scheme completion, the WUG becomes responsible for its operation and management. Every WUG has established its own rules and regulations to keep the scheme running smoothly, and plays a key role both in O&M and in distributing water among members (Table 5E).

Table 5E — Institutional Structure for O&M of Irrigation Schemes

Village	Ownership	Members	Status
Diusa	Collective-WUG	26	20 women engaged in group farming across four groups; O&M collection Rs. 50/month. Some members have recently begun farming individually, weakening the institution; external support is needed.
Pujargaon	Collective-WUG	13	Group farming; women have collectively developed the high-density orchard; regular saving in practice; well-defined written bylaws; a profit-sharing mechanism is yet to be tested.
Chopriyalgaon	Individual	3	One family manages the plot; orchard-vegetable intercropping in practice; self-funded O&M and purchase of new assets.
Saabli	Collective-WUG	32	Large group; all members contributed 10% at implementation; monthly O&M collection in practice; the water distribution system is poorly designed, creating a risk of future disputes.
Taliya	Collective-WUG	15	Active group; members collect and deposit monthly charges (Rs. 20 in lean months, Rs. 100 in peak months, Feb–Jun); a caretaker is appointed for O&M during peak irrigation season.
Utirchha	Individual	1	Family decides on crop selection; self-funded O&M and purchase of new assets.
Kyara	Collective-WUG	5	Close family members farming a shared patch collectively; self-funded O&M and purchase of new assets.
Monisakri	Collective-WUG	13	Functional group, though disputes over monthly charges and asset repair persist; the governing body decides in line with the group's bylaws.
Rampur	Collective-WUG	42	All families actively involved; pump operating hours and per-family irrigation days are well defined; wildlife crop damage is a major concern; monthly O&M collection in practice.
Simoldi	Collective-WUG	20	WUG is defunct this year; the surface pump was damaged in a 2025 flash flood in the Asiganga. The government is renovating the older Guhl channel, and farmers now have an alternative irrigation option.
Silla	Individual	1	Pump is in operation; self-funded annual maintenance and repair; other farmers in need also rent irrigation services.

In Diusa, four women's groups organized themselves in 2020 to begin collective farming; after the scheme was handed over, all women continued to collect monthly O&M dues, though some members have recently begun farming individually, weakening group cohesion and letting maintenance issues emerge. In Pujargaon, 13 women started group farming by establishing the high-density orchard; nine of the thirteen remain actively involved in O&M, the group holds regular meetings for monthly collection, and its bylaws direct 20% of orchard profit into the group account for O&M. In Saabli, 32 households are WUG members with regular O&M collection in practice; the scheme was handed over to the WUG in 2025, and since all assets are new, maintenance issues remain limited for now, though fragmented land raises the risk of future water-distribution disputes. In Taliya, all 15 women members remain actively involved in O&M after handover, paying a tariff scaled to actual O&M need, with a caretaker appointed each summer to ensure equal distribution among members. In Monisakri, all 13 beneficiary households are WUG members; the group now manages the scheme independently, regularly collecting O&M funds — including a seasonal tariff from 3–4 migrant families during their stay in the village — though three families' failure to deposit their original 10% contribution remains a live source of dispute. In Rampur, the WUG has operated and managed the scheme since handover, with all members collecting O&M tariffs regularly under the governing body's oversight. In Simoldi, 20 families were WUG members, but the group has become defunct since the solar pump's 2025 flash-flood damage; with the state renovating an older Guhl channel as an alternative, O&M collection has lapsed.

The study team in discussion with Water User Group members during a village field visit.

5.3.1 Key Observations and Recommendations

1. Community participation during DTR preparation for the irrigation scheme should be ensured, so that farmers are conversant with all technical aspects of the scheme and can readily operate and manage it once it is handed over.
2. Community contribution at the time of irrigation intervention needs to increase; this is essential to making the community accountable for future investment in operation and maintenance.
3. In villages such as Diusa and Taliya, women hold a strong position within the WUG and are also responsible for selecting cash crops and marketing produce; in these villages, women play a larger role in household financial decisions. In villages such as Kyara and Saabli, by contrast, women's role in WUG decision-making and in marketing farm produce remains limited, confined largely to cultivation itself.
4. At present, the WUG's role is largely confined to operating and managing the irrigation intervention. There is a case for expanding its role and responsibilities to include agronomic planning and management — protecting agricultural land, selecting cash crops and marketing farm produce.
5. Regular handholding support is needed to help WUGs keep the water source, storage tanks and distribution pipes clean. Mountain water carries a high total dissolved solids (TDS) load, which can promote algal and other aquatic growth that shortens the life of pipes, drips and sprinklers.
6. The present practice of monthly O&M collection is unpopular with members, particularly in months when irrigation is not in use. A shift to crop-season-based tariff collection, tied to crop production, should be introduced instead, with the WUG deciding the seasonal tariff in consultation with members, based on farm income.

5.4 Sustainability of Interventions — Efficiency and Effectiveness

5.4.1 Source Sustainability

The catchment areas of most perennial streams, rivers and water sources studied lie within Reserved Forest, where treatment work can only be carried out in collaboration with the Forest Department; community involvement in the protection and management of reserve forest land remains limited. As Chapter 3 sets out in detail, streamflow varies significantly between peak and lean seasons, and collaborative work with both the Forest Department and the community is required to identify, treat and protect recharge zones for long-term source sustainability. The Uttarakhand government's Spring and River Rejuvenation Authority (SARRA) has been formed specifically to lead this kind of collaborative rejuvenation and conservation work across the state's Dhara, Naula, streams and rivers, and this study sees close coordination with SARRA as a priority.

Structures built along streams and rivers are highly vulnerable to flash floods and carry a significant risk of structural damage during the monsoon (Table 5F). In Kyara, a 15–20-metre-high Guhl near the water source was washed away in the last monsoon season; in Simoldi, the solar-powered surface pump was severely damaged by a flash flood in the Asiganga in July 2025.

Table 5F — Source Types and Catchment Area

Source Type	Catchment Area	Water Source Risk	Remarks
Perennial stream / river	Large catchment, mainly Reserved Forest, high risk of degradation	High risk of damage from flash flood	Collaboration with the Forest Department is required for treatment and protection
Natural spring	Relatively well-defined catchment, good scope to treat areas in Van Panchayat and private land	Lower risk to the source, can be readily protected	Good scope for treatment and protection in community and private land

The catchment of a natural spring is generally smaller and better defined than that of a stream or river, and community involvement in its protection and management tends to be stronger where the catchment lies in Van Panchayat forest. In such areas, identifying the recharge zone and treating and protecting it should form part of the irrigation intervention itself: in Saabli, where the catchment was treated ahead of the irrigation intervention, source discharge showed a rising trend rather than the decline seen elsewhere. Natural spring sources carry comparatively little risk overall, since most of their catchment lies within Van Panchayat or private land and can be protected through straightforward source-protection measures and proper tapping from source to collection chamber.

Further demonstration and action research are needed to identify, treat and sustain sources within their catchments. Collaborative action — especially with the Forest Department — is required for geohydrological mapping of springs, followed by treatment of the recharge zone, whether on private or forest land, using appropriate engineering and vegetative interventions, followed by proper maintenance and protection to ensure the source's long-term sustainability.

5.4.2 Optimizing Source Water Utilization

There is good scope to optimize water availability at the source through more effective collection and storage, as set out in Chapter 3. Because solar-powered lift schemes can operate for up to eight hours a day, storage capacity at the source needs to be designed to match this operating window, as in Monisakri and Rampur (Table 5G).

Table 5G — Water Availability vs Water Storage at Source

Village	Type of Pump	Storage at Source (L/day)	Per-Day Water Availability (L)
Monisakri	Submersible pump	15,000	18,720
Rampur	Submersible pump	10,000	23,040
Simoldi	Surface pump, diversion chamber	20,000	72,000
Kyara	Surface pump, diversion chamber	15,000	46,080

5.4.3 Performance of Solar Pumps

Surface pumps face a high risk of siltation damage and require regular cleaning and maintenance; submersible pumps perform more consistently and carry fewer maintenance issues, with observably higher operational efficiency in the field. Source discharge can often be increased simply by collecting water more completely: in Rampur, where the source is a marshy area, discharge of 16 LPM could readily be raised to 20 LPM by capturing flow from all discharge points across the marsh.

5.4.4 Operation and Maintenance of Different Irrigation Interventions

Table 5H — Operational and Maintenance Issues by Intervention Type

Type	Operation	Maintenance
Gravity-based irrigation	No operational cost beyond labour	Maintenance carried out as needed
Solar lift-based irrigation	No operational cost beyond labour	Maintenance carried out as needed
Petrol-based lift pump	Around Rs. 1,080 for 8 hours' operation, pumping 90 KL of water	Annual maintenance required

Given the high operating cost of petrol-driven pumps, solar-powered pumps are the better fit for mountain conditions; further demonstration and action research is needed to promote solar-powered lift irrigation at different capacities and in different combinations.

5.5 Rainwater Harvesting for Irrigation

Most villages in Uttarakhand depend on rainfed agriculture and lack a nearby water source, facing scarcity even for drinking water through the summer; in such villages, rainwater harvesting and its proper management may offer a viable route to critical irrigation. Annual rainfall patterns recorded in the rain-shadow area of Bhawan and the temperate area of Chamba both show only two to three months of low rainfall in the year, with the remaining months receiving ample rainfall — leaving good scope to collect and store rainwater across most of the calendar. In Chopriyalgaon, a progressive farmer has attempted exactly this, collecting rainwater in a 25 KL LDPE tank for cash-crop irrigation; because he has not been able to build a proper catchment area for rainwater harvesting, however, the tank still depends on filling from the drinking-water tap stand. There is ample scope to explore rainwater harvesting in rainfed areas in different combinations, and further demonstration and action research is needed on harvesting rainwater to retain soil moisture and support suitable cash crops.

Figure 5A — Rainfall Pattern (mm): Rain shadow Area (Bhawan)

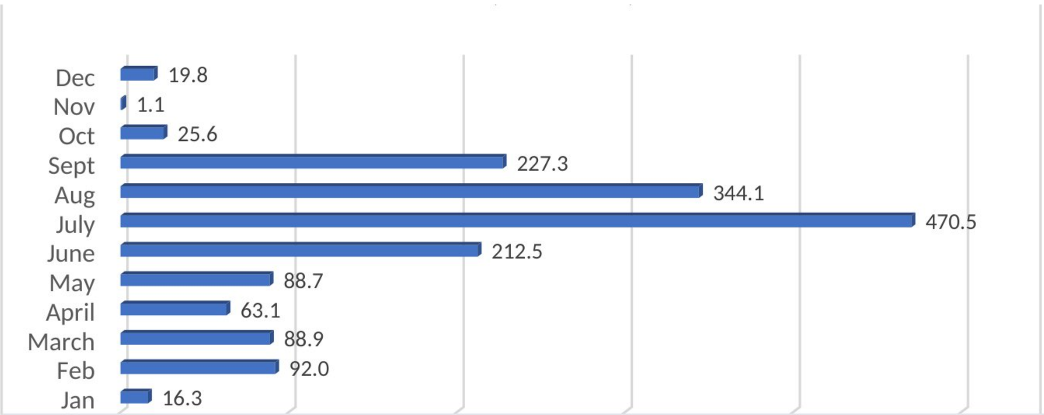
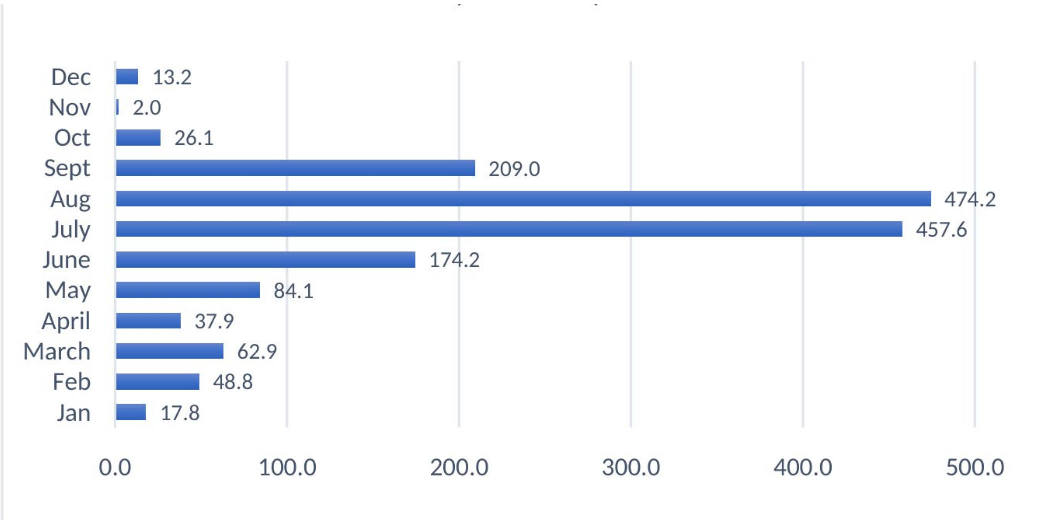


Figure 5B — Average Rainfall (mm) in Temperate Area (Chamba)



5.5.1 Water Storage Structure and Capacity

In some study villages — Diusa and Rampur among them — daily water availability exceeds storage capacity, leaving significant scope to improve irrigation efficiency simply by expanding storage (Table 5I).

Table 5I — Water Storage Structure and Capacity

Village	Type of Storage Tank	Storage Capacity (L/day)	Per-Day Water Availability (L)
Diusa	LDPE tank	25,000	57,600
Rampur	Existing FC tank	20,000	19,200
Pujargaon	Syntax tank	5,500	24,480
Saabli	RCC tank	40,000	27,360

Future storage capacity will be designed against actual water availability at the source. In Kyara, before 2022, the farmer relied on a single 30 KL tank; two additional tanks built since have lifted storage to 95 KL, raising per-Nali water availability from 7,500 to 14,000 litres — now sufficient for year-round crop irrigation (Table 5J).

Table 5J — Status of Water Storage at Kyara Village

	Before 2022	After 2022
Guhl discharge (LPH)	1,920	1,440
Guhl + solar discharge (LPH)	0	2,160

	Before 2022	After 2022
Water storage capacity (L)	30,000	95,000
Per-Nali water for irrigation (L)	7,500	14,000

In some villages, such as Taliya and Diusa, LDPE tanks have reached the end of their service life and are now leaking; pipeline leakage elsewhere is reducing efficiency and effectiveness by an estimated 20%.

5.6 Water Distribution for Irrigation

In most study villages, other than Pujargaon and Chopriyalgaon, farmers use HDPE pipes for irrigation and generally favour surface irrigation; the concept of supplementary irrigation designed for efficiency and effectiveness in maintaining soil moisture has not yet percolated down to farmer practice. Although an underground HDPE distribution network has been installed across 60 Nali of land in Kyara, farmers there still use open pipes rather than sprinklers for irrigation. Overall, this study finds significant scope — in the order of 20–40% — to raise irrigation efficiency by adopting a more efficient, effective water distribution system.

Drip irrigation in orchards has been successfully demonstrated in Pujargaon and Chopriyalgaon, though the system performs less efficiently and effectively at Chopriyalgaon than at Pujargaon (Table 5K).

Table 5K — Water Supply Through Drip Systems

Drip Irrigation (L/year)	Pujargaon	Chopriyalgaon
Total water supplied (L/yr)	5,40,000	1,05,000

Sprinkler adoption for irrigation remains limited, with farmers generally preferring pipes; low adoption reflects concerns over sprinkler quality, suitability for topographic conditions, and maintenance. A further limitation is the absence of any soil-moisture record: without one, irrigation is at times excessive and at other times insufficient. Implementing a soil-moisture monitoring system to determine actual crop water requirement would materially improve the efficiency and effectiveness of crop irrigation. Given how limited current demonstrations of distribution systems are, further action research is needed to assess their efficiency and impact across a wider range of conditions.

5.6.1 Selection of Crop as per Water Availability

In some vegetable-growing villages, farmers already select crops with an eye to their water requirement: in Kyara, Silla and Chopriyalgaon, villagers prefer the less water-intensive pea crop over potato, and sow pea at the onset of the monsoon for an autumn harvest — an efficient way of using available soil moisture. The main issues observed relating to crop irrigation are: uneven irrigation across terraced fields; water-distribution difficulties on fragmented landholdings; the labour required for crop irrigation; variation in water requirement and irrigation frequency by crop; and an estimated 20% crop damage caused by the shifting of pipes during irrigation. Further demonstration and action research are needed across water distribution systems, crop irrigation practice and soil-moisture management, to optimize crop production.

5.7 Returns

5.7.1 Cost-Benefit Analysis: Kyara Village, Vegetable Production

Kyara village is engaged in the commercial cultivation of vegetables and spices. A total investment of Rs. 18.45 lakh was incurred to establish solar lift irrigation, construct a storage tank and lay water-distribution lines;

average annual crop production cost, excluding family labour, was around Rs. 45,000. In 2025, total crop production reached 277 quintals, with a market value of Rs. 12.97 lakh. On this trajectory, farmers reach breakeven in the second year of crop production (Table 5L).

Table 5L — Cost-Benefit Analysis: Kyara Village, Vegetable Production

Particular	Year 1	Year 2	Year 3	Year 4
Investment cost (Rs.)	18,44,240	—	—	—
Annual crop production cost (Rs.)*	45,000	50,000	55,000	60,500
Total annual cost (Rs.)	18,89,240	50,000	55,000	60,500
Total production (kg)	27,710	30,481	33,528	36,881
Total market value (Rs.)	12,97,160	14,26,876	15,69,563	17,26,519
Net profit from total cost (Rs.)	-5,92,080	7,84,796	15,14,563	16,66,019
Per household income (Rs.)	-1,18,416	1,56,959	3,02,913	3,33,204

* Cost of family labour is not included.

5.7.2 Cost-Benefit Analysis: Pujargaon, High-Density Apple Orchard

In Pujargaon, a high-density apple orchard has been developed on 20 Nali of land at a total investment of around Rs. 19 lakhs — roughly Rs. 95,000 per Nali. An eight-year business plan has been developed for the Shri Nagendra Dutt Saklani self-help group's orchard. Fruit production has already begun in the third year, at 52 quintals, and optimum production is expected from the eighth year onward; the orchard is projected to reach breakeven in its fifth year (Table 5M).

Table 5M — Cost-Benefit Analysis: Pujargaon High-Density Apple Orchard (Rs., unless noted)

Particular	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Total
Establishment cost (Rs. lakh)	18.96								18.96
Recurring cost/Nali (Rs.)	10,000	10,000	10,000	36,000	40,000	70,000	80,000	80,000	12,500 avg.
Total cost/Nali (Rs.)	19,06,400	10,000	10,000	36,000	40,000	70,000	80,000	80,000	23,92,400
Marketable production (Qtl/20 Nali)			52	91	130	156	234	286	1,521 (cum.)
Total market value (Rs.)			5,20,000	9,10,000	13,00,000	15,60,000	23,40,000	28,60,000	1,52,10,000
Net profit from total cost (Rs.)			-14,06,400	-5,32,400	7,27,600	14,90,000	22,60,000	27,80,000	1,08,78,800
Net profit, group (20%) (Rs.)					1,45,520	2,98,000	4,52,000	5,56,000	25,63,520
Net profit, farmers (80%) (Rs.)					5,82,080	11,92,000	18,08,000	22,24,000	1,02,54,080
Total turnover (Rs.)	-	-			7,27,600	14,90,000	22,60,000	27,80,000	1,28,17,600
Per HH income (Rs.)								3,08,889	14,24,178

- Per-Nali establishment cost: Rs. 94,820.
- Per-plant establishment cost: Rs. 1,459.

- Break-even is projected for the fifth year.

5.8 Sustainability of Interventions

Overall, this study finds that the support-irrigation systems established in the study villages are of real value to farmers: with irrigation water available, crop production has risen by 2 to 3 times, substantially increasing farmer income from crop production. The village community will generally continue to maintain and operate the irrigation system at its own cost, and discontinues it only if an alternative irrigation source becomes available — as in Simoldi, where the state minor irrigation department's renovation of the damaged Guhl has left villagers uninterested in repairing the solar pump, given that repair would require transporting it to the nearest city, Haridwar.

Sustaining support-irrigation systems in the mountains over the long run requires efficient management of the entire water ecosystem: water source catchment area treatment, source protection, proper water storage structures, effective water distribution systems, and the cultivation of high-value cash crops matched to actual water availability.

5.9 Conclusion

1. Where landholding is consolidated, the individual or group of individuals owning the irrigation system self-invests in any repair needed, and operational and management issues are comparatively rare. In fragmented landholdings, farmers participate in a WUG to operate and manage the system, and have also pooled funds for maintenance; differences of opinion among members nonetheless often lead to conflict, making regular members' meetings essential to updating rules and regulations as required. Community participation during DTR preparation should be ensured so that farmers understand the scheme's technical aspects well enough to operate and manage it themselves after handover, and community contribution at the time of intervention should increase, to build the accountability that sustains future investment in O&M. Crop-season-based tariff collection, tied to crop production, should replace the present monthly collection model, with the WUG setting the seasonal tariff in consultation with members based on farm income.
2. Creating support-irrigation infrastructure is a cost-effective intervention, but it is also a composite one — catchment area treatment, source protection, installation of the irrigation system itself, a water storage structure, and a water distribution and crop-production system all have to come together. Because it is difficult to secure funding for all of these from a single source or project, work should be planned in a phased manner, or through a plan-convergence approach that draws on different line departments for different components. Sustaining support-irrigation systems in the mountains over the long run depends on managing the entire water ecosystem efficiently: catchment treatment, source protection, proper storage structures, effective distribution systems, and cultivation of high-value cash crops matched to water availability.
3. Demonstration and action research are needed to identify, treat and sustain sources within their catchments. Collaborative action — especially with SARRA — is required for geohydrological mapping of springs, followed by treatment of the recharge zone on private or forest land, using appropriate engineering and vegetative interventions, and followed by proper maintenance and protection to ensure the source's long-term sustainability.
4. Further demonstration and action research are needed across water distribution systems, crop irrigation and soil-moisture management to optimize crop production. Farmers presently rely on HDPE pipes and generally prefer surface irrigation. There remains significant scope — in the order of 20–40% — to raise irrigation efficiency by adopting a more efficient, effective distribution system; the concept

of supplementary irrigation, designed for efficiency and effectiveness in maintaining soil moisture, has not yet percolated down to farmer practice. Serious work is needed to reduce distribution losses and to raise crop output per drop of water applied.

5. Sprinkler adoption for irrigation remains limited, with farmers generally preferring pipes over sprinklers, owing to concerns over sprinkler quality, suitability for topographic conditions and maintenance burden. Demonstrations of water-distribution systems remain limited; further action research is needed to assess their efficiency and impact across a wider range of conditions.
6. The absence of a soil-moisture record means irrigation is at times excessive and at other times insufficient. Implementing a soil-moisture monitoring system to determine actual crop water requirement would materially improve the efficiency and effectiveness of crop irrigation.
7. Most villages in Uttarakhand depend on rainfed agriculture and lack a nearby water source, facing scarcity even for drinking water through the summer. In such villages, rainwater harvesting and its proper management may offer a viable route to critical irrigation. This is a critical area for future action research and piloting, and is essential to the long-term stability and sustainability of livelihood interventions across the Himalayas.

Chapter 6: Recommendations

Chapters 3 to 5 set out, in detail, the evidence and village-level reasoning behind this study's conclusions. Rather than repeat that material, this chapter draws it together into a single, prioritized set of recommendations, organized by theme, for use by CEDAR, the IWMI-TATA Water Policy Research Program, Himmotthan and other implementing agencies planning the next phase of investment in Himalayan water interventions.

A. Source Sustainability

1. Treat catchment identification and recharge-zone treatment as a mandatory, budgeted component of every irrigation scheme, not an optional add-on — the single clearest finding of this study is that the one village which treated its recharge zone (Saabli) saw source discharge rise, while every village that did not saw it fall.
2. Design every support-irrigation project against a 20-year output horizon, rather than the shorter planning windows evident in several current DTRs.
3. Priorities solar-powered lift irrigation, sized to local topography, for the substantial volume of water that lies below settlements and farmland and cannot be reached by gravity — solar carries no recurring fuel cost, against roughly Rs. 1,080 for an 8-hour day of petrol-pump operation.
4. Where a catchment falls within Reserved Forest, initiate joint geohydrological mapping and recharge-zone treatment with the Forest Department and the newly formed Spring and River Rejuvenation Authority (SARRA) — both essential co-implementers that current schemes have under-utilized.
5. Where infrastructure sits along a stream or river, design explicitly for flash-flood risk (siting, protection works, storage location) rather than treating flood damage as an unforeseeable event; two of the twelve study villages lost their lift-irrigation asset to flash floods within the study period.

B. Storage

1. Size every storage tank against measured source discharge, not preliminary estimate — several study villages under- or over-built storage relative to what their source could actually deliver.
2. Adopt a moderate-sized (20–30 KL) underground ferro-cement or RCC tank as the default design for mountain conditions, reflecting farmers' own stated preference for durability, seismic safety and low maintenance, while continuing to pilot alternatives.
3. Commission dedicated piloting of rainwater-harvesting storage and distribution for the upland villages that have no nearby water source and remain wholly rainfed — currently the least-served segment of villages encountered in this study.

C. Distribution

1. Redirect a meaningfully larger share of future investment toward the distribution system — the last mile between tank and root zone — where this study finds the largest untapped efficiency gain: an estimated 20–40% of water is presently lost to transmission and inefficient application.
2. Pair every decentralized storage tank with an individual-level distribution system matched to terraced-field topography, so farmers can irrigate on their own schedule, matched to crop need.
3. Redesign drip systems intended for annual vegetable crops (not permanent orchards) so they can be removed and reassembled with less labour across crop rotations — the main reason farmers who trailed drip on vegetables reverted to open-pipe irrigation.

4. Adapt sprinkler layout and equipment specification to mountain terrain and crop-growth stage before further promotion; Saabli's experience shows sprinklers work well at germination but become impractical, and labor-intensive to dismantle, once the crop matures.
5. Introduce simple soil-moisture monitoring at the pilot scale, to replace guesswork with a measured basis for irrigation scheduling.

D. Cropping Pattern and Crop Production

1. Actively promote intercropping of temperate orchards with off-season vegetables, and short-duration, off-season vegetables and spices more broadly, to raise gross cropped area and income on Uttarakhand's very small average landholdings.
2. Promote 'group farming' as the default institutional model wherever landholding is fragmented — Diusa's women's groups demonstrate that fragmentation need not be a barrier to cash-crop conversion if farmers can be organized to cultivate collectively.
3. Treat wildlife-proof fencing (chain-link, topped with solar fencing) as integral to every irrigation intervention, not a separable cost — cash-crop cultivation without it is not viable in most study villages.
4. Establish extension services for integrated pest and nutrient management (IPNM) alongside irrigation, to arrest the rising, poorly informed use of fertilizer and pesticide that is now driving up both production cost and long-run soil-health risk.
5. Support the replication of well-executed high-density orchard models (Pujargaon) over poorly executed ones (Chopriyalgaon), by making planting-material quality, technical supervision and post-planting maintenance funding non-negotiable components of any future orchard-establishment programme.

E. Institutions and Financing

1. Raise the community contribution above the prevailing ~10% norm in a phased way, now that farmers have seen irrigation's income effect and have expressed greater willingness to invest — a stronger financial stake is the most direct lever available for improving long-run O&M discipline.
2. Replace monthly O&M tariff collection with a crop-season-based tariff tied to the timing of farm income, to reduce the member arrears and disputes that monthly collection is generating in several WUGs.
3. Widen WUG mandates beyond irrigation O&M to include agronomic planning and marketing, and use villages such as Diusa and Taliya — where women already play a leading role in both — as the reference model for expanding women's role in scheme governance elsewhere.
4. Build a lightweight, low-cost technician and repair network for solar-pump maintenance; the lack of local technical capacity is a recurring driver of both scheme downtime and — as in Simoldi — communities' eventual loss of confidence in solar assets after a single failure.

F. Priorities for a Phase II Study

This study's principal methodological limitation is timing: fieldwork fell within the monsoon, when farmers do not irrigate, so most findings on water use, production and income rely on recall rather than concurrent measurement. A concurrent Phase II, running March–November 2026 to capture the full cropping and irrigation calendar, should prioritize the following action-research questions, each already identified in this report as needing further field-tested evidence before it can inform policy or design at scale:

1. Rainwater harvesting, storage and distribution systems appropriate to genuinely rainfed conditions, for villages with no accessible water source.
2. Solar lift pumps of varying capacity, matched to appropriate storage design, O&M arrangement and flash-flood-safe siting.
3. Water-efficient distribution systems — redesigned drip for rotational vegetable crops, adapted sprinklers, soil-moisture-based scheduling — paired with improved agronomic practice to lower production cost while protecting soil health and biodiversity.

Findings from this Phase II would both validate the conclusions reported here and generate the field-tested evidence needed to influence irrigation policy and design at scale — the ultimate purpose of this study.

Chapter 7: Case Studies

The twelve village case studies below give the underlying, on-the-ground detail behind the cross-village findings reported in Chapters 3 to 5. Each is presented with a summary table of the intervention's key parameters, followed by a narrative account of what the study team observed and what villagers themselves reported.

7.1 Nald Village, Bhatwari Block, Uttarkashi District

Rainfed Subsistence Agriculture — Unirrigated Comparison Village

Parameter	Detail
Location	13 km from Uttarkashi district headquarters, Bhatwari block; three revenue villages, 163 households, population ~1,200
Intervention	None — retained as the study's rainfed comparison case
Land	15 ha (750 Nali) total agricultural land, of which 3 ha (150 Nali) is cultivable wasteland; average holding ~4.5 Nali/household, highly fragmented
Farm income (per HH/yr)	~Rs. 18,300 — the lowest of any study village

Nald's agricultural land is split into two parcels, Pinola and Tard, between which Rabi and Kharif crops rotate; some land is deliberately kept fallow each Rabi season. Farmers grow a diverse basket of crops locally known as Barahnaja — cereals, millets, pulses and vegetables — mainly for household consumption, and around 95% still plough with bullocks. All farming is organic, relying solely on manure, and crop mulching for soil-moisture conservation remains standard practice. Women form the core agricultural workforce; men's involvement is largely confined to ploughing and harvest.

Average crop production across the village works out to about 75 kg per Nali, and farm income of roughly Rs. 18,300 a year falls far short of covering household needs, so families supplement it with livestock products, seasonal labour, and work in hotels and roadside dhabas during the tourist season. Villagers describe crop losses to wildlife — monkeys, wild boar and bear — as having risen sharply, compounding an already unreliable monsoon. As Ms. Shakuntala Devi, a village resident, put it: “We are cultivating the fields only because we live here and don't want to keep our land fallow; there is no reward for our hard work.”

Forest and hillside terrain surrounding Nald's agricultural land.

A traditional stone-and-timber house in Nald village.

7.2 Monisakri, Duggada Block, Pauri Garhwal District

Solar-Powered Lift Irrigation

Parameter	Detail
Location	Baghi Choti Gram Panchayat, Duggada block; 27 families, population ~80
Intervention	5 kW solar-powered submersible lift irrigation, installed by Himmotthan, 2020-21
Infrastructure	Two 7.5 KL RCC collection tanks at source; 16 solar panels; submersible pump and control panel; 20 KL geomembrane storage tank (80 m vertical lift, 32 mm underground HDPE); 350 m HDPE field-distribution pipeline
Cost	Rs. 3.5 lakh total; 10% community contribution
Outcome	Crop production per household rose from 1 Qtl/Nali to 3.1 Qtl/Nali; annual income rose from Rs. 46,600/HH to Rs. 1.71 lakh/HH

Monisakri's traditional water source, locally called Gugun, sits about 250 metres below the village and has long served drinking, washing and livestock needs, with a substantial surplus flowing past unused. In 2020, Himmotthan and the village community agreed to capture that surplus for irrigation, installing a solar lift scheme to move water from source to a geomembrane tank atop the village's agricultural land.

Average discharge at source is 780 litres an hour, giving roughly 18,700 litres a day; the pump runs for eight hours daily, delivering around 570 KL of water a month. Farmers distribute this among themselves on a rotation basis, with two farmers typically irrigating each day and a seven-day gap between a given farmer's turns. The scheme has brought 100 Nali of land — belonging to 13 households — under irrigation, allowing a shift from traditional or fallow cultivation to vegetables and spices, with gross sown area rising to 200 Nali a year.

A 13-family water user group manages the scheme, with norms for monthly tariff collection, though disputes over timely maintenance payments recur. Group President Mrs. Uma Devi reported that the submersible pump was damaged once and had to be sent to Delhi for repair, at a cost of around Rs. 9,000 — a reminder of how far villagers must travel for even routine servicing. Water is also wasted at source and during field irrigation, and the group flagged an urgent need to identify and protect the source's catchment area, given a rapid decline in discharge that mirrors the pattern seen across most of this study's Reserved-Forest and civil-land catchments.

Solar panels and the collection tank installed above Monisakri village.

Villagers and the study team at the solar lift irrigation site in Monisakri.

7.3 Diusa Village, Duggada Block, Pauri Garhwal District

Gravity-Based Support Irrigation

Parameter	Detail
Location	Duggada block; 65 households, population ~230
Intervention	Gravity-fed diversion from the Khola stream, installed by Himmotthan, 2021
Infrastructure	Diversion chamber; 850 m HDPE pipeline; 25 KL LDPE tank; field-distribution pipeline, serving the 200-Nali Parkhet parcel
Cost	Rs. 2.83 lakh total; 10% community contribution
Outcome	1,035.5 quintals of vegetables and spices produced annually, valued at ~Rs. 39 lakhs; individual family income of roughly Rs. 1.5 lakh a year

The Parkhet parcel — 200 Nali owned by 26 families, half a kilometre from the village near the Khola stream — was entirely barren before 2020. In 2021, a Himmotthan team held a series of meetings with the village's women and secured their agreement to bring the land under cultivation. A gravity scheme followed: water diverted from the stream through an 850-metre HDPE pipeline to a 25 KL LDPE tank at the top of the parcel, and a distribution pipeline for field irrigation.

Women organized themselves into groups, and with block-office support, chain-link fencing was completed across the whole parcel, followed by field clearing and ploughing. The 200 Nali were divided among the 26 women — about 7.7 Nali per family — who now cultivate vegetables and spices collectively, distributing water on a rotational basis. Discharge at source is 2,400 litres an hour, giving roughly 1,700 KL a month, though the tank's own storage capacity is only 750 KL; farmers commonly bypass it altogether during the dry season, connecting straight to the main pipeline, and irrigate 5–6 times a year on average.

Four women's groups formed a user group to operate and maintain the scheme, but six members have recently left to farm individually — a shift that has weakened group cohesion and let maintenance issues emerge. Group President Ms. Mamta Devi reported that the LDPE sheet has begun leaking and the distribution pipe is broken in several places, while wildlife damage has increased as the chain-link fencing has weakened in places. Women asked for support to repair and maintain existing assets, together with continued technical backing to help reorganize the group around collective farming.

Women of Diusa village in discussion with the study team at the Parkhet land parcel.

Terraced fields at Diusa brought under cultivation through the gravity irrigation scheme.

7.4 Rampur, Chaukhutiya Block, Almora District

Solar-Powered Lift Irrigation

Parameter	Detail
Location	Ramganga river valley, Chaukhutiya block, ~10 km from the block office; 160 households, population ~740; Chaukodi hamlet — the intervention site — has 42 households and 200 Nali of unirrigated, fragmented land
Intervention	5 kW solar-powered submersible lift irrigation, installed by Himmotthan, 2021-22
Infrastructure	Marshy-land source, channeled into a 10 KL underground RCC collection tank; 5 kW submersible pump (70 m lift, 40 mm HDPE); 20 KL RCC storage tank (built earlier under a government scheme); 300 m HDPE (32 mm) distribution pipeline
Cost	Rs. 3.45 lakh total
Outcome	Per-Nali production rose from 0.5 Qtl (unirrigated) to 1.5 Qtl; household income from Rs. 15,700 to Rs. 65,660 a year

Water discharge at source is 15 LPM, yielding 21,600 litres a day at the sump; the solar pump runs for eight hours daily, lifting water into the 20 KL tank for distribution. Farmers irrigate their fields in rotation, starting from the farthest end of the parcel; a full cycle across the whole land parcel takes about a month, after which the rotation begins again from the same point.

Cultivation shifted from entirely rainfed to irrigated conditions, and average wheat, paddy, millet and pulse production all rose accordingly, with the largest gain in vegetables — from 1.3 to 3.6 Qtl/Nali. Even so, only around 20% of households have shifted to cultivating vegetables as a cash crop; the study team found the absence of adequate crop-protection measures — chiefly against wildlife — to be the main reason most farmers have not made the switch, even with irrigation now in place.

A water user committee comprising all households operates and maintains the scheme successfully. Group President Mr Heera Singh Rawat identified several avenues for improvement: additional source-tapping and a larger sump to raise discharge further; an additional storage tank; and a shift toward water-saving devices such as sprinklers, given the wastage and uneven irrigation the study team observed with open-pipe distribution. He also stressed that chain-link fencing, topped with solar fencing, is a precondition for wider cash-crop adoption, and called for regular technical support to help farmers settle on an appropriate package of practices for sustained cash-crop production.


The solar-powered submersible pump installation at Rampur's water source.


A farmer filling an irrigation channel at Rampur.

An irrigation hose distributing water across a field at Rampur.

7.5 Kyara-Badait Village, Raipur Block, Dehradun District

Gravity and Solar-Based Lift Irrigation

Parameter	Detail
Location	Kyara Gram Panchayat, Raipur block; 126 households' village-wide, intensively engaged in vegetable production. Badait hamlet, 1.5 km from the main village: 5 families, population ~41, 60 Nali of land across 45 terraced fields (SW-facing, sandy loam)
Intervention	Gravity diversion (Guhl) from the Bandal gadhera stream, cemented in 2012; 5 kW solar lift scheme added by UREDA, 2022; underground HDPE distribution network installed by Himmotthan, FY 2021-22
Infrastructure	Three RCC tanks (95 KL combined) at the top of the parcel; 1.5-inch HDPE solar-lift line (~100 m head, 4–6 hrs to refill); 350 m of 50 mm HDPE distribution pipe with gate-valved outlets, buried ~2 feet along field bunds
Cost	Rs. 16 lakhs (solar lift, UREDA) + Rs. 2 lakhs (distribution network, Himmotthan, 10% community contribution)
Outcome	Total crop production rose from 127 to 277 Qtl/year; household income from ~Rs. 94,000 to Rs. 2.59 lakh a year

Before 2022, farmers relied solely on gravity flow through the Guhl (1,920 LPH) into a 30 KL storage tank. The 2022 solar lift addition raised combined discharge to 2,160 LPH and, together with two new tanks, lifted total storage to 95 KL — raising monthly water availability from about 9 lakh litres to 14.25 lakh litres and making year-round irrigation possible for the first time. Farmers typically run the solar pump from March to June, when demand peaks.

The distribution network Himmotthan installed the same period interconnected the tanks via HDPE pipe and buried a 350-metre network with gate-valved outlets across the terraced fields — a level of distribution infrastructure notably more complete than most other study villages. Farmers grow a wide variety year-round: peas, ginger, potato, onion and coriander in Rabi, with a small area of wheat and barley; radish and leafy coriander from May to July; and, more recently, an off-season vegetable pea from August to November — a short-duration addition driven by strong market demand and favorable pricing. Gross sown area rose from 85 to 135 Nali, and the area under cereals fell correspondingly.

Mr Rajpal Singh Rawat, a village resident, recalled that before the intervention around 10 Nali of land lay fallow for want of water; with the solar scheme and expanded storage, water is now available year-round for the full 60 Nali. He credited the buried distribution network with cutting water waste by around 60% and reducing the labour cost of irrigation, in turn supporting greater cash-crop intensity and self-employment. He also raised a concern this study shares: the growing frequency of cloudbursts, which caused heavy losses to agricultural land and crops across the valley during the 2025 monsoon, underscoring the need to treat and protect the entire catchment for the scheme's long-term sustainability.

Terraced fields at Kyara-Badait under year-round cultivation since gravity and solar-lift irrigation were combined.

RCC storage tanks and solar panels installed above Kyara-Badait village.

A farmer in his irrigated field at Kyara-Badait.

7.6 Utirchha Village, Ramni Block, Pauri Garhwal District

Rainwater Harvesting and Tap Stand Water for Irrigation

Parameter	Detail
Location	Along the Kotdwar–Ramni road, ~20 km from Kotdwar town, Pauri Garhwal
Intervention	Household-level rooftop and tap-stand rainwater harvesting
Infrastructure	10 KL LDPE-lined household tank, built 2021-22
Outcome	56 quintals of vegetables and spices produced annually on 21 Nali; annual income of Rs. 2.37 lakh (2025)

Utirchha illustrates a broader pattern of change in Uttarakhand's hill villages: the original settlement, once located about 2 km below the road in a valley, has been largely deserted as households have either relocated along the roadside following construction of the Ramni road, or migrated to the plains altogether. Agricultural land in the old village site now lies fallow.

Ms Lata Devi, who relocated to a 15-Nali roadside plot, has kept 8 Nali under supplementary irrigation. In 2021-22 she built a 10 KL LDPE-lined tank that collects rooftop rainwater together with surplus supply from the drinking-water tap stand, and uses it to irrigate cash crops — potato, onion, garlic, ginger, capsicum and brinjal — on her homestead land. Across 21 Nali under vegetable and spice cultivation, she produced 56 quintals in 2025, worth Rs. 2.37 lakh. In her own words, the supplementary irrigation facility now lets her earn substantial income from a limited landholding that, without it, would have yielded next to nothing — a small-scale but concrete illustration of what household-level rainwater harvesting can achieve even without a dedicated catchment.

A covered nursery bed in an irrigated field at Utirchha.

7.7 Silla Village, Raipur Block, Dehradun District

Petrol-Operated Water Lifting Pump

Parameter	Detail
Location	~30 km from Dehradun, the last village on the Maldevta–Silla motor road; 105 families, population ~552
Intervention	5.5 HP petrol-driven Honda lift pump, provided by Himmotthan to Mr Prem Dutt (Silla-Khatta hamlet), 2021-22
Infrastructure	Portable 28 kg pump, lift capacity 25–30 m, no storage tank required
Cost	Rs. 32,000; 10% beneficiary contribution
Outcome	Average production of 2 Qtl/Nali with irrigation; 80 quintals annually; farmer income of Rs. 2.26 lakh a year from vegetables and spices

Silla's land — 19 hectares (950 Nali) in total, of which 7 hectares (350 Nali) is irrigated — supports year-round vegetable cultivation across most households. The pump Himmotthan provided to Mr Prem Dutt lifts water directly from the perennial stream near the village as needed, at a pumping capacity of roughly 9,000 litres an hour: run for eight hours, it can irrigate 10 Nali of land, lifting 90,000 litres of water, at a fuel and maintenance cost of about Rs. 1,080 a day.

Mr Dutt uses the pump to irrigate his own 15 Nali of upland fields, growing potato, onion, beans, green pea and coriander among vegetables, and garlic and ginger among spices. He described the petrol-driven pump as best suited to valley locations with ample stream flow — its light weight makes it easy to move, and because no storage tank is needed, the system is simple to operate. He has used the pump for five years with only routine maintenance (annual oil change and repairs as needed), and four or five other farmers in the hamlet now also rely on it to irrigate their own fields, effectively functioning as a shared community asset despite its individual ownership.

Mr Prem Dutt with the petrol-driven water-lifting pump at Silla.

7.8 Simoldi Village, Bhatwari Block, Uttarkashi District

Solar-Powered Surface Pump Lift Irrigation

Parameter	Detail
Location	Uttraon Gram Panchayat, Asiganga valley, ~10 km from Uttarkashi district headquarters; 50 households, population ~200
Intervention	5 kW solar-powered surface lift pump, installed by Himmotthan, 2021-22 — now non-operational
Infrastructure	16 solar panels near the riverbed feeding a surface pump (70 m lift); 20 KL geomembrane storage tank; 50 mm HDPE feeder pipe; 100 m HDPE (32 mm) distribution pipeline
Cost	Rs. 5.4 lakh total; 10% community contribution
Outcome	Per-Nali production rose from 0.8 to 1.7 Qtl; household income from Rs. 21,000 to Rs. 78,600 a year — before the scheme's 2025 flood damage

Simoldi lifts irrigation water from the Asiganga River, whose flow varies sharply between the dry and monsoon seasons and periodically floods its catchment after heavy rainfall. At full operation, the solar pump ran for about eight hours a day, lifting roughly 19,000 litres daily — 570 KL a month — bringing 2 hectares (100 Nali) under irrigation. Farmers adopted mixed cropping under the new scheme: wheat on most of the land in Rabi, paddy in Kharif, and vegetables on only about 30% of the irrigated area.

A 20-household water users' group initially collected a monthly tariff for O&M, but collection lapsed progressively after the implementing project's withdrawal, and the group had become fully defunct by the end of 2024 — even before the scheme suffered physical damage. In June 2025, heavy siltation during a flash flood in the Asiganga severely damaged the surface pump; with no repair facility nearby and farmers unwilling to transport the pump elsewhere for repair, it remains out of service.

Mr Narendra Singh Rana, a village resident, recalled that before 2013 the village relied on a well-developed network of Guhl channels for irrigation, all destroyed in that year's flash-flood disaster; the state's minor irrigation department has, in 2025, resumed repairing these Guhls. With the prospect of this alternative source, farmers have lost interest in repairing the solar pump — though Mr Rana voiced continuing concern about the long-term viability of the repaired Guhls too, given the risk of landslides near the source. Simoldi is, in short, this study's clearest cautionary case: a technically sound scheme whose institutional and physical resilience both gave way once external support and streamflow stability could no longer be assumed.

Solar panels installed above the Asiganga river at Simoldi.

Villagers beside the storage tank repaired after the 2025 flash flood at Simoldi.

7.9 Taliya Village, Kotabagh Block, Nainital District

Gravity-Based Support Irrigation System

Parameter	Detail
Location	Kotabagh block, 12 km from Kotabagh market; 55 families, population ~310. Taliya-Malla hamlet, above the road: 15 families, 4.6 ha of agricultural land, 1.5 ha irrigated
Intervention	Gravity-fed diversion from the Chunnipani spring, installed by Himmotthan, 2020-21
Infrastructure	32 mm HDPE pipeline (~3 km from source); 25 KL LDPE tank with field-distribution line; 8 individual farmers' own 7.5 KL tanks
Cost	Rs. 2.72 lakh total; 10% community contribution
Outcome	Crop production nearly tripled, from 3 to 6 Qtl/Nali; family income from crop sales rose from Rs. 32,770 to Rs. 1,33,800 a year

Fifteen families, cultivating 75 Nali of land, benefited directly from the scheme, which taps the Chunnipani spring on Van Panchayat land about 3 km from the village. Farmers formed the Laxmi Irrigation Users Group, which adopted bylaws for proper operation and equitable water distribution: the main tank is open for two hours a day, with families irrigating on a rotational basis — three families a day from September to January, dropping to two families a day from February to June, when water availability is lower. During the summer peak, the group collects Rs. 120 per member and appoints a caretaker to manage operations and ensure equal distribution.

With irrigation available, farmers converted the area formerly under cereals and pulses to vegetables and spices, averaging about 5 Nali per family. Onion bulb and seed cultivation, introduced after the intervention, has since become a major Rabi-season crop. Group President Ms Prema Devi described the gravity-based LDPE tank as having “given us hope to live with pride in a rainfed area,” crediting it with generating real income from agricultural operations that previously offered little. She attributed the scheme's continuity to the consensus the group has built around its own rules, regulations and community contributions for O&M — precisely the institutional discipline this study finds is often the difference between a scheme that lasts and one that does not.

Construction of the LDPE storage tank at Taliya.

An irrigated vegetable field at Taliya.

7.10 Saabli Village, Jaunpur Block, Tehri Garhwal District

Gravity-Based Support Irrigation

Parameter	Detail
Location	Along the Bhawan–Uttarkashi road, ~20 km from the Thatyur block office; 65 households, population ~300; average landholding 0.2 ha (10 Nali), mostly marginal farmers
Intervention	Gravity-fed diversion from the Paniyarkhala perennial stream, with sprinkler distribution and catchment treatment, installed by Himmotthan, 2023-24
Infrastructure	450 m HDPE pipeline to a 40,000 L storage tank; 1,200 m HDPE distribution line; 1,600 sprinklers distributed to farmers; 4.7 ha of catchment treated with contour trenches, percolation pits, check dams and tree planting
Cost	Rs. 5.20 lakh for the irrigation system; a further Rs. 5.2 lakh invested in catchment treatment, 10% community contribution
Outcome	Source discharge rose from 13 to 17 LPM after catchment treatment — the only rising trend recorded in this study; crop production rose from 151 to 498 quintals (0.5 to 1.7 Qtl/Nali); household income from Rs. 15,000 to Rs. 61,000 a year

Saabli occupies a distinctive place in this study: it is the one village where catchment treatment — contour trenches, percolation pits, check dams and tree planting across 4.7 hectares of community forest — was carried out as part of the intervention itself, ahead of the irrigation works. The result was a measured rise in source discharge, from 13 to 17 LPM, at a time when every other study village with an untreated catchment recorded a decline. This is, in the study team's assessment, the clearest single piece of field evidence that catchment treatment is not a nice-to-have alongside irrigation infrastructure, but a precondition for its long-run sustainability.

With irrigation available, roughly half of Saabli's households have begun cultivating vegetables, and the area under cereals is gradually giving way to vegetables and spices, though most farmers still hold only about 5 Nali of highly fragmented land. Around 10 sprinklers were distributed per Nali, delivering about 4,500 litres of water per Nali across an average of four irrigations a year — some 5,400 KL of water in total across the scheme. A 32-household water users' group operates and manages the irrigation structures and distribution, with all households paying a monthly tariff; water distribution begins from the farthest end of the parcel, with five people a day permitted to irrigate.

Despite the sprinklers provided, farmers generally prefer pipe-spray irrigation in practice, and — in the absence of any soil-moisture measurement — irrigation across the field remains uneven. The group's president noted that farmers are gradually shifting from cereals and pulses to cash crops, constrained mainly by their small, terraced and fragmented fields, and that changes to cropping pattern continue to depend on collective decisions aimed at protecting crops from wildlife.

A drip irrigation irrigated field at Saabli, the one study village where catchment treatment produced a measured rise in source discharge. Vegetable and high-density apple intercropping

The storage tank at Saabli, built after the source catchment area was treated.

Terraced fields at Saabli, above which the source catchment was treated.

7.11 Pujargaon, Jaunpur Block, Tehri Garhwal District

Gravity-Based Drip Irrigation — High-Density Apple Orchard

Parameter	Detail
Location	~60 km from Dehradun via the Maldevta–Kaddukhal road; 45 households, population ~350; 124 ha of Van Panchayat forest
Intervention	High-density apple orchard with gravity-fed drip irrigation, established by the Shahid Nagendra Dutt Saklani women's self-help group with Himmotthan support, 2022-23
Infrastructure	Spring source in Van Panchayat forest (17 LPM discharge); 500 m HDPE feeder pipeline; three 5,500 L Syntax tanks; 4,500 m of 32 mm HDPE mainline with 16 mm laterals; pressure-compensating drippers (4 LPH, 1/plant); woven weed-mat mulch; GI-pole trellis with UV-stabilised hail net; chain-link perimeter fence
Cost	Rs. 19.06 lakh total; 10% community contribution
Outcome	98% plant survival; 52 quintals of fruit sold in 2025 (Rs. 5.2 lakh); orchard-floor pea intercrop earning a further Rs. 1.8 lakh a year; peak production of 286 Qtl/year projected from Year 8

Thirteen women of the Shahid Nagendra Dutt Saklani self-help group agreed, after a series of meetings with Himmotthan, to collectively plant and maintain a high-density apple orchard on 30 Nali across six terraced fields — 1,500 plants, laid out to a technical specification that included 2-foot-deep trenches at 3-metre spacing, compost- and fertilizer-filled planting pits at 1-metre intervals, and a varietal mix of 45% Delicious, 50% Gala and 5% pollinizer, planted in a pattern designed for cross-pollination. Planting material was sourced from a certified nursery recognized by IHBT Palampur, the Uttarakhand Department of Horticulture and the Department of Biotechnology, Government of India — a level of quality assurance this study found in few other orchard interventions.

The orchard's drip system draws from a Van Panchayat forest spring, tapped into a storage chamber and piped 500 metres to three Syntax tanks, from which a 4,500-metre HDPE network delivers water to pressure-compensating drippers at each plant — irrigating once a month across seven months of the year. Beyond irrigation, the orchard's establishment reflects a comprehensive package: a woven weed mat to control weeds, moderate soil temperature and conserve moisture; a GI-pole trellis supporting dwarf rootstocks (M9, M26); UV-stabilised hail netting; and chain-link fencing, with pruning, manuring and maintenance carried out annually by group members.

The results speak for themselves: 98% plant survival, average plant height of 8.9 feet, stem diameter of 5.2 inches and 28 branches per plant — figures that compare favourably with the similarly aged but far less carefully executed orchard at Chopriyalgaon (see Chapter 4). Fruiting began in the third year; the group sold 52 quintals of fruit in 2025, worth Rs. 5.2 lakh, and also earns Rs. 1.8 lakh a year from a winter pea crop grown beneath the trees. Group President Mrs Pushpa Devi and fellow members are optimistic about the orchard's trajectory: fruit production is expected to peak from the eighth year at around 286 quintals annually, generating an estimated Rs. 28 lakhs in net profit a year, of which the group's bylaws direct 20% to a maintenance fund and 80% to members directly. The group regards the pilot's careful execution and management as the template for extending group farming to other fragmented mountain landholdings.


The Shahid Nagendra Dutt Saklani self-help group and the study team at the Pujargaon high-density apple orchard, under its hail-protection netting.

The Shahid Nagendra Dutt Saklani women's group with the study team in the high-density apple orchard.

Drip irrigation lines laid along the planting rows at Pujargaon's apple orchard.

7.12 Chopriyalgaon, Chamba Block, Tehri Garhwal District

Rainwater Harvesting-Based Support Irrigation

Parameter	Detail
Location	~12 km from Chamba town along the Chamba–Mussoorie road; 90 households, population ~404. Chunnipani hamlet, above the road: a separate 60-Nali parcel farmed by three families, at 2,000 masl, SE-facing, ~1,600 mm average annual rainfall
Intervention	High-density apple orchard (state Horticulture Department, Apple Mission, FY 2021-22) intercropped with vegetables, irrigated from rainwater harvesting and drinking-water tap-stand surplus
Infrastructure	Four storage tanks (3 near the farmer's house, 42 KL combined, plus a 25 KL LDPE tank on the agricultural parcel); drip irrigation along orchard rows; surplus drawn from the Surkanda drinking-water lift scheme (built under the Jal Jeevan Mission), which serves ~11 villages
Cost	Rs. 6.5 lakh (Horticulture Department) + Rs. 1.2 lakh farmer contribution for plantation operations
Outcome	Orchard survival 76% (120 of 500 plants died); 15 quintals of fruit sold in 2025 (Rs. 1.5 lakh); vegetable intercropping remains the dominant income source, at Rs. 8,39,300 a year village-wide

Progressive farmer Mr Khushi Ram Dabral farms a separate 60-Nali parcel at Chunnipani hamlet, where he has built four water storage tanks — three near his house, holding 42 KL combined, and a 25 KL LDPE-lined tank on the agricultural land itself — to harvest rainwater and store surplus water drawn from the nearby Surkanda drinking-water tap stand, which runs for about an hour a day. In FY 2021-22, the state Horticulture Department supported him in planting 500 apple plants on 26 Nali, with a drip system installed along the rows and connected to the storage tanks; critical irrigation runs for seven months of the year, though tank capacity limits dripper flow to just 1 litre an hour at each point — too little to reliably retain root-zone moisture through the driest months.

As Chapter 4 sets out in more technical detail, this orchard's performance falls well short of the comparable Pujargaon planting: average plant height of 6.4 feet, stem diameter of 3.3 inches and 15.4 branches per plant, against a 76% survival rate. Mr Dabral was candid about why: he had limited technical know-how at the time of planting, and, with hindsight, believes the layout could have fit the same number of plants into 11 Nali rather than 26. GI poles for hail netting were erected but never properly fitted, leaving fruit exposed to damage during the 2025 fruiting season, when 15 quintals were harvested and sold for Rs. 1.5 lakh. Given the orchard's underperformance, Mr Dabral now plans to replace some of the failed plantings with persimmon, a hardier, less water-intensive species requiring less care.

Vegetable intercropping remains, by contrast, a genuine success at Chopriyalgaon and the mainstay of local farm income: winter pea across 58% of the cultivated area, a range of Kharif vegetables on 30 Nali, and radish, green coriander and pea through the monsoon, cultivated from nurseries established each March–April. Across the wider village, gross vegetable area of 130 Nali yields 114 quintals annually, worth Rs. 8,39,300 a year, or roughly Rs. 2,79,770 per household. Mr Dabral observed that the temperate region's generally good year-round rainfall helps retain soil moisture naturally, with supplementary irrigation needed mainly to bridge dry spells in summer — and that, with that critical irrigation in place, rainfed-area farmers can grow off-season vegetables and temperate fruit that command a real premium in the market.

A rainwater storage tank at Chopriyalgaon.

The study team walking through the intercropped orchard at Chopriyalgaon.

Mr Khushiram Dabral, a progressive farmer of Chopriyalgaon, in his vegetable field.

References

This revised edition draws on the following external sources to corroborate and contextualize claims made in the report, in addition to the study's own primary and secondary field data. Full citations, with the specific claim each source supports, appear as footnotes at the relevant point in the text.

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