Received: 27 February 2026 | Accepted: 03 August 2026 | Published online: 24 August 2026

DOI: 10.53550/ijsc.v54.i2.232

ORIGINAL ARTICLE

Indian Journal of Soil Conservation

Crop Productivity and Sustainable Agricultural Systems in Snow-Receiving Hazardous Himachal Mountains: A Review

Anand Verdhan[1,*]

[1]Former Scientist, DRDO and National Institute of Hydrology, Roorkee, Associate Prof. CWRS (PU), Prof. DCE, Khetawas Sadarpur, Nalanda, Bihar 811101, India

Corresponding Author:
E-mail: anand_indra3@yahoo.co.in

Handling Editor:
Dr. Rajive K. Singh

Key words:
Crop productivity
Climate variability
Hazards
Himachal agriculture
Snow-receiving mountains
Soil erosion

ABSTRACT

The snow-receiving regions of Himachal Pradesh — Lahaul-Spiti, Kinnaur, upper Kullu and parts of Chamba, lying broadly above 2,000 m amsl — sustain agriculture under severe constraints: short growing seasons, snowmelt-dependent irrigation, fragmented holdings, steep erodible slopes and recurrent natural hazards. This paper reviews published literature, government statistical reports, and institutional assessments for the period 2000–2025 to asses crop types, productivity, investment cum developmental schemes, natural resources, hazard, and sustainability constraints having accessible intermittent and scattered evidences in the concerned and related regions. Reported snow season warming of about 1.2°C during1982 -2007 at Solang (2,500 m), nearly 50 percent reduction in seasonal snowfall, and earlier snowmelt have disrupted the kuhl-fed irrigation on which the region depends; only about 12 percent of Kullu's net sown area is irrigated. Yields remain well below national and international benchmarks — wheat about 1.85 t ha^{-1} (State average, 2023), barley 1.5–2 t ha^{-1}, seed potato 20–30 t ha^{-1} — while apple productivity has been declining at about 0.183 t ha^{-1} per year. Public investment is substantial and rising, yet reported scheme progress for 2010–2015 shows near-uniform annual increments that warrant independent verification, and no published study relates investment to measured productivity gain in snow-receiving tracts. The review concludes that drought-resistant cum cold-tolerant and high-value crops, micro-irrigation and kuhl restoration, soil, snow and water conservation, afforestation and hazard-sensitive planning together offer a workable adaptation pathway, but that altitude-stratified monitoring, controlled crop trials and independent scheme evaluation are prerequisites for sound policy. Limitations of the underlying data are stated explicitly throughout.

1 | INTRODUCTION

Himachal Pradesh covers 55.67 lakh ha in the western Himalaya and spans several agro-climatic zones. Population density is 123 persons/km², one-third of the national average (2011 Census). Notified forest land accounts for 66.43% of the State, although only about 25% of its area carries actual tree cover (Section 1.2); glaciated terrain subject to freeze and thaw covers 13.32%, and desert or degraded mountain nearly 50%. About 95% of the population depends on some 9.51 lakh ha of cultivable land, of which 5.38 lakh ha is net sown; cropping intensity was reported at 176.6% for the early 2010s (Anand, 2015) and at about 169% more recently (MTD, 2022). Gross irrigated area is 1.87 lakh ha, leaving 81.5% of cultivated land rainfed (Anand, 2015). There is little scope for extending the cultivated area: steeper slopes degrade rapidly, while rural-to-urban migration is increasing the extent of fallow land. Land holdings are small — marginal 70%, small 18%, semi-medium 8.8%, medium 2.9% and large 0.3% of 9608 holdings — which restricts the use of modern machinery.

The seasonal lowest-average snowline altitude (SLA) rose from about 1,400 m amsl in the 1980s to 1800 m in the 2000s, while the maximum or equilibrium SLA rose from 4,800 m to 5,100 m (Verdhen *et al*., 2015). Snow-receiving regions within the cold desert and dry temperate zones are accordingly taken here to extend from 2,000 to over 6,000 m. Kulkarni (1991), from satellite imagery of Himachal glaciers, estimated a water equivalent of nearly 165 km³. Nijampurkar *et al*., (1993) found that snow and ice of the Chhota Shigri glacier, which feeds the R. Chandra, carry chloride at a concentration 1.9 times that of sodium by weight (402 mg/l in snow, 185 mg/l in ice), a ratio close to that of seawater. Notarnicola (2024) compiled a 23-year dataset of yearly snow cover area (SCA), snow cover duration (SCD), first snow day (FSD) and last snow day (LSD) from MODIS imagery at 500 m resolution over the global mountain regions delineated by the GMBA shapefile, allowing seasonal snow dynamics, land-use and vegetation change and streamflow to be tracked.

The region receives heavy snowfall intermittently from November to February and up to May in higher altitudes, has a short growing season from April to October, and faces limited water availability as glaciers retreat and snowfall declines. Agriculture is the primary livelihood of 71% of the population and is constrained by soil erosion, natural and induced hazards, climate variability, and low soil fertility. Hazards affect the agricultural economy in two ways: through recurrent direct damage and through the uncertainty they impose on development. Rapid development is threatening heritage, agriculture, ecology and environment (Pandey, 2023).

1.1 | Agro-Climatic Characteristics of Snow-Receiving Regions

Chowdhury *et al*., (1993) divided India into 15 agro-climatic zones and identified crop varieties and durations suited to each zone, recommending multi-cropping, intercropping, and climate-resilient varieties to reduce the risk of extreme events. In the cold desert zone, temperatures range from −25°C in winter to 25°C in summer; irrigation depends critically on snowmelt, and the short growing season imposed by snow cover restricts cropping to quick-maturing, for cold-tolerant species (Verma & Vashisth, 2025). Steep high-altitude terrain is prone to landslides and avalanches; soils are rocky, acidic, low in fertility and erosion-prone, and only 2–10% of the geographical area is cultivable, so careful management is essential (ICAR, 2016; NITI, 2022). The terrain is highly vulnerable to natural and man-made disasters due to its hydro-geological setting, seismic activity, and hurried, unplanned construction, which together trigger avalanches, cloudbursts, and landslides and damage roads, buildings, cultivation, lives, and livelihoods (HPSDMA, 2025). Yangchan *et al*., (2019) reported rise in temperature by 3 °C during 1973-2008 in Ladakh and employed water scarcity management for snowy arid zone of Leh and Ladakh where even surface water quality has gone bad and localized water table gone down by 42 m due to tourists and camp.

The exceptionally heavy rain spell of September 1988 over north-west India matched the October 1955 rainstorm in magnitude and areal extent, crossed the Pirpanjal range, produced the heaviest rain depths in the Chenab basin and caused unprecedented flooding in Jammu and Kashmir (Dhar & Nandargi, 1991). Against this, Thapliyal and Kulshrestha (1991), analysing a century of rainfall, surface temperature, atmospheric pressure and total ozone data for India, found neither a systematic climate trend nor evidence of ozone depletion. Loukas and Quick (1993) showed, for 1972–1995 in the coastal mountains north of Vancouver, that rainfall depth per event increases up to mid elevation and then decreases at higher elevations. Reduced snowfall and earlier snowmelt under a changing climate have led to water scarcity (Verdhen *et al*., 2011; Gupta, 2022). Kumbhar and Rastogi (1992) simulated peak runoff for the Ramganga mountain watershed using linear reservoir theory, and Eldho (2009) coupled a finite-element rainfall–runoff solution with remotely sensed land use and land cover and GIS-derived drainage, channel, elevation, and slope data. Hagg *et al*., (2006) predicted higher spring discharge from earlier and intense snowmelt, followed by water deficit once the snow cover has gone, in the hot dry summer months when irrigation and domestic demand peak. HEC-HMS and the SRM (Martinec) model are best suited to Himalayan snow conditions and to climate-change detection (Rao *et al.,* 1989; Rango, 1992; Verdhen *et al.,* 2013; Poudel, 2021), while HEC-RAS produces flood maps and flood-range characteristics.

HIGHLIGHTS

- Solang Valley (2,500 m amsl) reveal snow-season climatic conditions typically over 25 years (1982-2007) showing warming by 1.2° C, snowfall decrease by 50% and early snow depletion.
- Farmers rely on barley; wheat and potato crops in snow dominated representable Lahail-Spiti district rather than market dependent pulses and mustered crops. Need to explore crop types in addition to Safron, heeng and vegetables.
- Water supply schemes for household and micro-irrigation are operational but snow and water conservation and storage are required taking lesson from Ladakh region.
- South of the Pirpanjal range having partial snow cover period, cloud burst and flooding than avalanche, damage control and state level crop productivity sustainability planning is warranted.
- Protection of forest in lower and plantation of traditional willow, Poplar and new cold resistant trees/bushes in higher snow receiving altitudes required for weather and soil protection.
- Reported scheme progress for 2010-11 to 2014-15 rises in near-uniform annual steps, leaving investment unlinked to measured productivity or to soil loss of 16–20 t ha^{-1} yr^{-1}.

1.2 | Forest Cover and Soil Erosion

Water erosion and landslides reduce soil fertility and disrupt connectivity across Himachal Pradesh. Traditional conservation practices — terracing, contour farming and agroforestry — protect fertile soil and stabilize slopes. Although 66.43% of the State is classified as forest land, 36.84% of that (with a further 2% unsurveyed) is pasture and alpine land above the tree line carrying no forest, so only about 29.5% of the State can be regarded as conventional forest and only 22.49–25% is actually under tree cover, against the 66% sought for hill areas by the National Forest Policy (DEST, 2025). Maurya *et al*., (2024), applying the RUSLE model to the Beas Valley, estimated the average soil loss at 19.9 t ha^{-1} yr^{-1} in 2023. Kanwar *et al*., (2024) concluded, based on a review of numerous area-specific soil-loss equations, that the universal soil loss equation (USLE) nomograph remains the most widely accepted and used. Soil erosion and landslides cause land degradation, loss of connectivity, debris deposition, and flash flooding, and pose a particular threat on mismanaged slopes with gradients steeper than 33%. Haldorsen and Kruger (1990) showed that the hydrological properties of tills depend on grain-size distribution, compaction, fracturing, particle orientation, and the occurrence of sorted sediments. Land-use planning that prevents degradation, desertification and erosion, and that reduces input costs, follows from matching use to slope: up to 30% for agriculture, 30–40% for horticulture and silvi-pasture, and above 50% for forestry (Chowdhury *et al.*, 1993).

Garkoti and Singh (1995) reported that with rise in Central Himalayas altitude, the forest biomass decreased from 308.3 ha^{-1} to 308.3 t ha^{-1} in Acer Cappadocicum Forest (2750 m altitude) to 40.5 ha^{-1} to 40.5 t ha^{-1} in Rhododendron Campanulatum forest (3300 m altitude). Adhikari and Rawat (2012) studied vegetation response to climate and found Deciduous-conifer or Blue Pine trees basal area at 3350 m altitude only 9 to 15 m^2 ha^{-1} and even more sparse tree density at 3650 m altitude basal area of Birch tree just 5 m^2 ha^{-1}. Gairola *et al.* (2025) envisaged that documentation of changes in the vegetation parameters can provide important insights on the impact of climate change but limited research has been conducted on the spatial patterns of vegetation along altitude in the sub-alpine zone of west Himalaya. While study should be encouraged to study vise-versa, impacts of forest cover depletion on regional climate. In lack of vegetation soil conservation is important. Singh *et al.* (2019) assessed the procedures like check dams, terracing etc. being used for soil conservation and revegetation in high altitude zones of cold desert of Leh-Ladakh and suggested biological measures viz., plantation of sea buckthorn and other existing plantations.

Singh and Sarkar (1994) framed soil conservation policy around the biotic and abiotic causes of biomass production. Kumari *et al.,* (2024) examined traditional agroforestry and farmer socio-economics in Baijnath tehsil (998–1,525 m amsl), reporting an average family size of 5.26, literacy of 89.3%, and a preference for government service alongside agriculture and cattle rearing; average holdings were 0.73 ha for marginal, 1.74 ha for small and 2.57 ha for medium farmers. Addressing holding size and off-farm employment is essential to sustainable development. The agri-silvi-horticulture (ASH) system gave the highest biomass production potential at 25.3 t ha^{-1} and the pastoral-silviculture (PS) system the lowest at 13.8 t ha^{-1}; such systems raise rural incomes by supplying fuelwood, fodder, timber, food grains, fibre, fruit, grasses and raw material for forest-based industry. Incomes would rise further with improved irrigation, replacing heavy dependence on rainfed cultivation. Uzoagba *et al.*, (2024) assessed the feasibility of using crop residues for bioenergy, a process that requires careful selection, management, and processing of crops. Agroforestry policy must be matched to regional socio-economic context. Steep land accordingly requires vegetative and engineering conservation measures — trenching, terracing, drainage, soil treatment and water harvesting.

1.3 | Suitable Crops in Snow-receiving Regions

Barley is the traditional cereal of high altitudes: drought-tolerant, undemanding of water and suited to cold, it is well matched to Lahaul and Spiti (Gupta, 2022). Wheat is also grown in the cold dry zone, benefiting from timely snowfall to retain soil moisture (NITI, 2022). The pseudo-cereals buckwheat and amaranth tolerate low-fertility soils and short seasons and carry nutritional and medicinal value. Local traditional potato varieties are adapted to high altitudes and require less water than commercial varieties. Black pea is a drought-tolerant pulse of high nutritional value and useful in rotations for maintaining soil health (Bahadur *et al*., 2022).

Off-season vegetables such as peas, cauliflower, and cabbage are rewarding cash crops but are water-intensive and require careful water management (Gupta, 2022). Saffron, a low-water, high-value crop suited to cold climates, has been successfully trialed in Kinnaur, Lahaul-Spiti, and Chamba under the Krishi Se Sampannta Yojana. Heeng is likewise a high-value, low-water spice crop for high altitudes (Kumar & Ramesh, 2018). Disease-free seed potato from Shimla, Kullu and Lahaul commands strong demand and good returns, and hops and chicory seed are viable with a growing market (Rawan, 2017).

Stone fruits such as plums and apricots are less water-intensive than apples and are well-suited for diversification (ICAR, 2016). Apple nevertheless remains the backbone of Himachal horticulture; it thrives in the snow belt but depends on consistent snow cover to meet its chilling requirement, and varieties such as Royal Delicious remain popular (ET, 2025). Olive, fig and pistachio are being promoted as emerging crops for their adaptability to cold, dry conditions and high market value (Rawan, 2017). With the Quality of seeds of suitable crops, integrated weed management (IWM) is also important for sustainable productivity, especially Phragmites weed, locally known as Dambu in cold arid zone of Ladakh (Raghuvanshi *et al.*, 2018 and 2023; Balihar and Dahiya, 2024). Meena *et al.,* (2023) conducted survey and found farmers of Ladakh depend upon traditional knowledge. The cold arid tracts, spread over in the northern states J&K, HP, UK & Sikkim mostly practices identical tradition and facing similar problems of food-grains production (Raghuvanshi *et al.*, 2019).

Mapfumo *et al*., (2025) attributed rising winter and spring air temperatures in the Canadian Prairie provinces to the conversion of snow precipitation to rain, and noted that the resulting increase in growing degree days and corn heat units has allowed corn cultivation to move northwards. Yield there depends on geographical, environmental (air and soil temperature), technological (machinery, fertilizer) and biological (disease, pest) factors, together with export markets and prices, transport costs, breeding and technological advance. Spring wheat (Triticum aestivum L.) accounted for 73% of Prairie wheat production in 2021, durum (T. turgidum L. ssp. durum) 14% and winter wheat 13%, on a total of 22.3 million t; barley (Hordeum vulgare L.), grown mainly in Alberta, British Columbia and Saskatchewan for malting and fodder, is affected like wheat by stem rust, while canola (Brassica napus L.), grown largely in Saskatchewan for oil, feed and biodiesel, makes Canada the leading exporter. The shallow winter snowpack over grain fields melts in spring and supplies soil moisture through the growing season, so any reduction in off-season precipitation, or a shift from snow to rain, alters soil moisture and can restrict later crop growth — the same mechanism that operates in the Himachal snow belt, and one that has led Prairie farmers to leave land unseeded in order to restore soil moisture, control disease and mineralise nutrients.

1.4 | Objective and Scope of the Review

A systematic review of the status, farming activities, infrastructure, investment, and productivity is a precondition for expanding agriculture, improving sustainability, and raising farmers' incomes in snow-receiving regions. Climate variability, natural and man-made hazards, water availability for households and fields, market access, and training and support all bear directly on communities living in remote and harsh conditions. Quantitative study of investment impact and income trends is needed if development strategy is to rest on a sound footing, yet the available surveys, reports and literature show that the problems and potential of these regions have not been worked out comprehensively at State, national or international level, and local people meanwhile face recurrent hazards, cultivation problems and, in some instances, exploitation by visitors and government-sponsored developers. The objective of this review is therefore to examine the agricultural systems, schemes, crop types, productivity, and marketing status of the snow-receiving mountain regions under a changing climate, and to evaluate the natural and human-made problems and their corresponding solutions in relation to the region's potential for sustainable development. Meeting that objective requires assessment of snow and forest cover, meteorological conditions, hazard mitigation, melt hydrology and opportunities for water resources development. The scope is confined to the snow receiving valleys of the Kullu and Lahaul-Spiti districts in the western Himalaya, drawing on adjacent states, globally available technologies and records.

2 | MATERIALS AND METHODS

2.1 | Study Area and Delineation

The review covers the snow-receiving tracts of Himachal Pradesh lying broadly above 2,000 m amsl, with primary attention to Kullu district (including the Solang and Parvati valleys), Lahaul-Spiti and Kinnaur, and secondary reference to comparable tracts of Chamba. Two sub-zones are distinguished throughout: the lower snow-receiving belt between about 1,500 and 3,000 m, which is seasonally snow-covered and largely horticultural, and the cold-desert belt above 3,000m, where cropping is limited to quick-maturing, cold-tolerant species. Temperature, snowfall and its period varies with altitude and mountain ranges. Seasonal fresh snow annually during November to April of 1980s experienced 4 and 15 m in about 15 spells and lowest weekly minimum temperature with elevation varies from -3 ^{o}C to -30 ^{o}C. Over four decades climate variability with rise in temperature has affected snow and rain ratio of precipitation, snow cover duration and water resources, agriculture and energy due to drastic degradation of forest cover. Official record shows forest cover area as 66%, while at present being reported as 23-25%.

2.2 | Sources Consulted and Search Approach

Snow receiving low and high altitude regions has been targeted to study the farming activities, crops, productivity, problems and damages faced due to hazards. Material was assembled during preparation of this review over years to 2025 from four classes of source. First, peer-reviewed literature was located through Google Search/Scholar and Research Gate using combinations of the study relevant specific terms, supplemented by citation tracking from key papers. Second, official statistics were taken from the Directorate of Economics and Statistics, Government of Himachal Pradesh, the State Economic Survey series, and departmental scheme reports. Third, institutional assessments were drawn from ICAR, NITI Aayog, HPSDMA, NABARD, CWC and the State Department of Environment, Science, Technology and Climate Change. Fourth, the author's own published snow-hydrology work and field experience in the Beas and Chandra basins, gained during earlier service with SASE (DRDO) and NIH, Roorkee, have been used. Emphasis was placed on the period 2000–2025; earlier work was retained where it provided the only available baseline, as in the case of the 1980s snowpack records.

2.3 | Inclusion-Exclusion and Treatment of Data

Material was included where it referred to Himachal Pradesh, or to comparable high-altitude tracts of Uttarakhand, Jammu & Kashmir or Ladakh, and where it addressed crop productivity, climate variability, water resources, hazards, soil conservation, forestry or agricultural investment. Opinions pieces unsupported by data, and repeated secondary reportage of a figure already traced to its primary source, were excluded. Where a value could be obtained only at State level, this is stated explicitly in the text, because State aggregates combine altitudes from about 300 m to over 6,000 m and cannot be read as representative of snow-receiving tracts; such values are presented as indicative rather than definitive. Comparative international yields are quoted without adjustment for mechanization, input use, variety or holding size and are offered only for order-of-magnitude context. Where ever possible statistical pooling has been attempted, otherwise the underlying studies differ in period, station, method and spatial unit.

2.4 | Declaration on the use of Artificial Intelligence

Generative artificial intelligence (Grok, X platform) was used with questions on crops, investment, disasters, water security, and projects like the Gyspa Dam at the initial scoping stage, to locate candidate sources and to draft summary text. No factual statement, numerical value or citation in this paper rests on an AI-generated output: each was subsequently traced to, and is cited from, its primary source, and material that could not be so verified was removed. The author accepts full responsibility for the content of the paper.

2.5 | Limitations of the Review

Three limitations should be borne in mind. Instrumental records for the snow-receiving belt are project based or scattered with departmental heads and overall sparse spatially, so the period of warming realization and its impact on seasonal snow (1980s to 2007) and altitudinal duration have been presented which can be stabilized or reversed with effective measures. Crop productivity and damage figures for Districts and or states levels referred to visualize the situation and implication in higher altitudes, Reported progress under government schemes could not be independently verified in the field, and is therefore reported as claimed progress as this technical review article is systematic rather than scoping framework followed d by Arksey and O'Malley (2005) and Levac *et al.*, (2010).

3 | RESULTS AND DISCUSSION

3.1 | Agricultural Systems, Investment and Productivity

State and central governments are consistently making plan and policies for the farmers and agricultural development schemes, but farmers are facing uncertainties.

3.1.1 | Sources of Investment

Investment in agriculture in the snow-receiving regions comes from three sources, of unequal weight. Farmers' own resources are severely limited: holdings average 0.59 ha, marginal farmers hold about 70% and small farmers 18% of the total, and on-farm capital formation is correspondingly small. Private credit is constrained by the tie between formal lending and land title, so that 41% of holdings below one hectare depend on informal sources such as moneylenders for seed and fertiliser; cooperative societies, 3,841 statewide, supply short- and medium-term credit and market produce, covering 93% of the rural population of Kullu (Deshpandey, 2017; Rawan, 2017). Limited transport infrastructure and poor market access further deter private investment. Government schemes are therefore the dominant source, and the State's allocation of 12% of plan resources to agriculture, the highest of any Indian State, is intended to close the gap (Rawan, 2017). Because the beneficiaries are overwhelmingly marginal and small farmers, scheme design has to ensure that they are not trapped or exploited by intermediaries or by investors with a vested interest.

3.1.2 | Government schemes and their reported implementation

The principal schemes operating in the snow-receiving districts are set out in Table 1. They fall into four groups: production support, through natural farming, protected cultivation and fodder; water, through micro-irrigation and kuhl maintenance; risk cover, through insurance and anti-hail netting; and enabling infrastructure, through soil-testing and bio-control laboratories, packing and cold-chain facilities and winter water supply. What the table also shows is what is absent: for none of these schemes is there a published assessment of physical verification, functionality or outcome specific to the snow-receiving belt.

TABLE 1 Principal government schemes bearing on agriculture in the snow-receiving districts of Himachal Pradesh.

Scheme	Purpose and support offered	Outlay / subsidy	Reported coverage	Source
Prakritik Kheti Khushhal Kissan Yojana (natural farming)	Chemical-free cultivation on low-cost organic inputs (FYM, vermicompost); training through KVKs (Krishi Vigyan Kendras)	Not separately reported	54,914 farmers on 2,451 ha by 2019-20; >90,000 trained and >5,000 ha converted by Nov 2020; target 20,000 ha and 9.61 lakh families by 2025	NITI, 2022; Rawan, 2017; Chandel *et al.*, 2020
Mukhyamantri Nutan Polyhouse Pariyojana	Protected cultivation of high-value off-season vegetables	₹150 crore total; ₹78.57 crore Phase 1 (2020-23); ₹22 crore 2022-23; 85% subsidy	5,000 polyhouses over 100 ha targeted; 2,522 reported built in Phase 1.	Himachalservices, 2022-23
Mukhyamantri Kisaan Evam Khetihar Mazdoor Jeevan Suraksha Yojana	Insurance against injury or death from farm machinery; supports safe mechanisation	Cover of ₹10,000 to ₹3 lakh	Not reported by district	Himachalservices, 2022-23
Uttam Chaara Utpadan Yojana	Fodder production; subsidy on seed, cuttings and chaff cutters for SC, ST and BPL farmers	₹6 crore (2017-18) with subsidy on seeds, cutters and cuttings	25,000 ha targeted	Himachalservices, 2022-23

continued on next page

Table 1 continued

Scheme	Purpose and support offered	Outlay / subsidy	Reported coverage	Source
Micro and traditional irrigation	Drip and sprinkler systems saving 60–80% of water; kuhl maintenance; conjunctive use of snowmelt and perennial sources	₹1,000 crore State irrigation budget, 2020-21; systems subsidized	Only 12% of Kullu net sown area irrigated mainly with Kuhls; 109,452 ha irrigated statewide	Verma and Vashisth, 2025; Deshpandey, 2017; ICAR, 2016; MTD, 2022
Soil health and organic promotion	Soil testing, bio-control, vermicomposting, organic certification, input distribution	Not separately reported	11 soil-testing laboratories; bio-control laboratories at Kangra and Mandi; 4 lakh vermicompost units; 7,200 t improved seed, 29,500 t fertiliser and 50,000 implements distributed	Rawan, 2017
Soil health and organic promotion	Soil testing, bio-control, vermicomposting, organic certification, input distribution	Not separately reported	11 soil-testing laboratories; bio-control laboratories at Kangra and Mandi; 4 lakh vermicompost units; 7,200 t improved seed, 29,500 t fertiliser and 50,000 implements distributed	Rawan, 2017
Risk cover and market infrastructure	Anti-hail netting for orchards; district input fund; packing house upgrade	50% subsidy on netting; ₹20 crore Kullu agriculture fund; ₹797.30 lakh from APEDA	Patlikuhl packing house (Kullu) upgraded for fruit and vegetable processing	Himachalservices, 2022-23
NABARD climate-smart project, Parvati valley	Glacial lake outburst flood risk reduction; water harvesting; resilient crops	₹20 crore by NABARD; ₹19.12 crore released by December 2022	Parvati valley of Kullu, including Salang	Himachalservices, 2022-23
Jal Jeevan Mission winter water schemes	Round-the-clock supply at temperatures to −20°C using three-layer insulated pipe laid 4 ft below ground	₹79.15 crore, of which ₹56.13 crore for Lahaul	24 schemes approved January 2024 — 11 in Lahaul valley including Jispa, 13 in Spiti, on the Chandra and Bhaga rivers and bore-wells	Bhandari, 2024

Outlays are as sanctioned or as reported by the implementing departments. Coverage figures are as claimed and, except where noted, have not been independently verified.

The year-on-year record of seven schemes related to natural farming over 2010-11 to 2014-15 (5 years) is given in Table 2, totaling 1,879.5 ha (annual average standard deviation of 23%) treated against erosion, 6,486 (annual average SD =17%) rainwater harvesting tanks, micro-irrigation over 15,652 ha (annual average SD =21%), 634,280 (annual average SD = 3%) soil health cards, 5,229 ha (with SD =11%) certified organic farm, 9,037 ha (with SD =26%) converted to organic and 83,275 (with SD =112%) vermicompost units (Anand, 2015; DEST, 2025). Two features of that series deserve comment. Soil health card issue is recorded as exactly 125,000 in each of three successive years, and organic conversion as exactly 2,000 ha in each of three successive years, while rainwater harvesting and micro-irrigation show similarly narrow variation, while programs spread across districts of widely differing terrain, budget release and farmer uptake would not normally deliver such uniform annual increments. Standard deviation is high in case of setting Vermicompost units indicate satisfactory implementation of all the 7 schemes in first two years and further require verification before investment. The same caution applies to the more recent reporting: Chandel *et al*., (2020) record the launch of a Sustainable Food Systems Platform for Natural Farming (SuSPNF) under PK3Y, with more than 90,000 farmers trained and over 5,000 ha converted by November 2020 against a stated intention to reach 12,000 ha from 2018 to 2021. The SuSPNF team during field visits was satisfied that farmers valued the disease resistance of playhouse protected cultivation and orchardists appraised an improvement in soil properties, and assured for market niche support in brand creation and in price setting.

TABLE 2 Reported progress of government agricultural schemes in Himachal Pradesh, 2010-11 to 2014-15 (compiled from Anand, 2015, for DEST, GoHP).

Scheme / intervention	Outcome measured (unit)	2010-11	2011-12	2012-13	2013-14	2014-15	Total
Treatment against erosion	Area treated (ha)	829.5	500	550	0*	0*	1,879.5
Rainwater harvesting	Tanks constructed (no.)	1,695	1,145	1,211	1,215	1,220	6,486
Efficient use of irrigation water	Micro-irrigation installed (ha)	3,100	4,252	2,500	2,800	3,000	15,652
Soil health management	Health cards issued (no.)	134,607	124,673	125,000	125,000	125,000	634,280
Promotion of organic farming	Farms certified organic (ha)	894	1,035	1,000	1,100	1,200	5,229
Promotion of organic farming	Area converted to organic (ha)	977	2,060	2,000	2,000	2,000	9,037
Promotion of organic farming	Vermicompost units set up (no.)	35,659	38,616	3,000	3,000	3,000	83,275

**Zero entries for 2013-14 and 2014-15 appear in the source as blanks and may indicate non-reporting rather than cessation of the program.*

3.1.3 | Management Practices and Knowledge Integration

Three lines of practice underpin these schemes. Integrated nutrient management rests on soil testing to identify deficiencies and the balanced (combined organic and inorganic fertilizers)–application of inputs through extension services to arrest soil degradation (Verma and Vashisth, 2025). Conjunctive use of fertilizers, manures and plant growth promoting rhizobacteria (PGPR) significantly influenced soil nutrient status and nutrient uptake pattern of cauliflower crop (Thakur *et al*., 2019). Agroforestry and perennial cropping reduce erosion improve water retention and enhance biodiversity: native willow and poplar planted alongside crops and roads stabilise slopes, while apple and stone fruit reduce soil disturbance (Bahadur *et al*., 2022); both willow and poplar have been tested in these tracts and wider planting could serve bioenergy security as well as erosion control. Traditional practice deserves updating rather than displacement — crop rotation, snowmelt harvesting, pre-winter irrigation to form a frozen surface layer that conserves moisture, jute bags tied around fruit trees against Indian gypsy moth, and clay-and-cow-dung slurry against apple canker (Verma & Vashisth, 2025).

3.1.4 | Productivity trends

Productivity means yield of crop depends on local variables like soil quality, altitude, climate conditions, irrigation/rain, seed varieties, market forces, farming practices. It is difficult to compare from region to region, especially in snow receiving areas. However, for insight available in government statistical records and online searches can give some picture and trends for snow receiving Sates within India and abroad. Crop productivity snow receiving regions are not available separately for Himachal as it matches with the state level records of 2023.

State and National level average productivity available for HP, J&K and UK for the year 2020-21 (Agricultural Statistics at a glance, 2022) indicate almost half for wheat in HP with respect to national (3384Kg ha^{-1}) but UK yield is comparable. Barley productivity is almost double of UK (978 Kg ha^{-1}). Again, Maize productivity in HP is 145 to 200 Kg ha^{-1} higher to the National Value of 2582 Kg ha^{-1}. Rice/Paddy is one-fifth times lower than the national. At international level wheat, Barley and Potato productivity can be compared. Although Russa, Canada and Switzerland are developed in their resources but national level wheat (3384 Kg ha^{-1}) a slightly higher than Russia (3210 Kg ha^{-1} in 2025) and nearly 500 Kg ha^{-1} lower than Canada (3920 Kg ha^{-1}), while the Barley and wheat productivity of Russia and Canada are almost same and nearly double of HP. Potato productivity of HP is nearly 25000 Kg ha^{-1} lower than Switzerland (34700 Kg ha^{-1}) but almost double of Russia.

The change in rate of yield over one and half decades (w.r.t year 2005-06 and year 2021) for the Wheat, Rice, Pulses and Oilseed (Agricultural Statistics at a Glance 2015 and 2022) has rising trend for the states HP, J&K and UK. Himachal shows relatively high rate of growth in yield especially in case of pulses and oilseeds. Due to warming climate early snow cover depletion can give an opportunity to increase the availability of crop area and rise in liquid precipitation ratio, but there are so many other factors, motivation and inputs involved depending upon farmers resources. Consequently, without under controlled conditioned experiments nothing can be related with the change in climate, which is induced by cutting trees and energy intensive life style. Indian Council of Agricultural Research Institutions and universities should try their best for the crops seed and plants environmentally compatible and sustainable to the snow receiving rugged regions.

Cultivable land amounts to 5.6 lakh ha, about 10% of the State, and in Lahaul-Spiti and Kinnaur only 2–10% of the land is arable. The area under food grains fell from 853.88 thousand ha in 1997-98 to 755.93 thousand ha in

2021-22 as cultivation shifted to vegetables and fruit (Himachal Services, 2022-23), a shift most marked in Kullu, where apple and off-season vegetables have displaced cereals. State cropping intensity is about 169%, with 4.042 lakh ha sown more than once, although altitude limits double cropping in Salang's, the higher Parvati valley (MTD, 2022). Gains have come from high-yielding varieties, protected cultivation and organic practice: polyhouses raise pea and tomato yields by 20–30% over open fields; natural farming is reported to lower input costs, raise profit by 22% and reduce apple scab incidence to 9.2% against 14.2% under chemical farming, with 25,000 farmers engaged and 4 lakh vermicompost units in support by 2021-22 (NITI, 2022; Rawan, 2017); and India's 5.71 million ha under organic certification by 2015-16, with Himachal among the leading States, brings premium prices to high-altitude growers (KSPB, 2016). Working against these gains are a decline in chill units of 14.98 units/yr and an associated fall in apple productivity of about 0.183 t ha^{-1} yr^{-1} over the decade preceding publication (Chandel *et al.*, 2013), together with the tribal economic structure and exposure to landslides, cloudbursts, and avalanches. Quality seeds are an important input necessary for agricultural productivity, and good quality seeds account for 20%-25% of increased crop productivity. Seeds are regulated by the Seeds Act, 1966. The Act regulates the quality, production, and sale of seeds. Although, due to cold climate pest control is not much warranted but weeds control persists. The Economic Survey 2015-16 noted an increase in pesticide and fertilizer residue impact being found in food products and water bodies.

3.1.5 | Crop yields and returns per hectare

Table 3 brings together the yield and return figures for the principal crops, along with the comparators against which they are usually judged and the basis for each estimate. Read together rather than crop by crop, three things follow.

TABLE 3 Reported yields, comparators and gross returns for the principal crops of the snow-receiving districts.

Crop	Principal tracts	Reported yield	Comparator	Gross return (₹ ha^{-1})	Basis of estimate and source
Wheat	Statewide; Kullu, Shimla, Lahaul	1,853 kg ha^{-1} (2023); 1,714 (2022); peak 2,033 (2017); 1,500–1,800 long-term	Haryana and Punjab >4,500 kg ha^{-1}	MSP ₹25.85 kg^{-1} as on 1st Oct. 2025 for year 2026-27	State average across all altitudes; Kullu 1,800–2,000 kg ha^{-1} extrapolated (CEIC data, 2000-2023)
Barley	Salang, Shimla, Lahaul	1,500–2,000 kg ha^{-1}	-	Not separately reported	District estimate; cold and drought tolerant (Himachal services, 2022-23)
Red rice	High hills of Kullu, as in Salang	0.8–1 t ha^{-1}; 1,100 ha statewide; 992.6 t yr^{-1}	-	30,000–50,000	District record; scope for more with a GI tag (HT, 2020)
Off-season vegetables (pea, cauliflower, cabbage, tomato)	Kullu; Lahaul-Spiti; Statewide	20–25 t/ha under protected cultivation; 7.85 lakh t on 41,500 ha (18.92t ha^{-1}); 16.53 lakh t on 76,947 ha (21.49 t ha^{-1}) statewide (2014-15)	+20–30% under polyhouse over open field	50,000–1,00,000 (2014-15); Increased cost declines profitability	Aggregates altitudes and methods (MTD, 2022; Kumar, 2017; Chandel *et al.*, 2013)
Seed potato	Lahaul; Salang of Kullu Dist.	20–30 t ha^{-1}	-	1,00,000–2,00,000	District record; premium reflects disease-free quality; Hamta development station (Rawan, 2017; Karun, 2021)
Apple	Kinnaur, Shimla, Kullu	Belt averages 8–12 t ha^{-1} (Kullu 8–10; Salang 6–8); State average c. 5.6 t ha^{-1}, falling 0.183 t ha^{-1} yr^{-1}	World average 20–25 t ha^{-1}	2,00,000–4,00,000; c. ₹3,500 crore to the State economy	Belt averages and State aggregate are not comparable (Chandel *et al*., 2013; Drishti, 2024; Karun, 2021; DEST, 2025;Wiki, 2007)
Saffron	Kinnaur, Lahaul-Spiti	1–2 kg ha^{-1}	-	5,00,000–10,00,000 at ₹2–3 lakh kg^{-1}	Trial plots under Krishi Se Sampannta Yojana; not yet commercial (H.P., 2022)
Heeng	Kinnaur, Lahaul-Spiti	0.5–1 kg ha^{-1}	-	2,00,000–5,00,000 Post-harvest loss and rising input costs	Trial plots; not yet commercial (Kumar and Ramesh, 2018; H.P., 2022; Drishti, 2024)

Returns are gross and refer to the periods covered by the cited sources; they are not adjusted for input costs, post-harvest losses, or transport. MSP = minimum support price; GI = Geographical Indication.

First, Wheat cultivation dominates in snow free zone and rest on State averages and the saffron and heeng entries come from trial plots. Any altitude-specific productivity drawn from the remaining rows is either related to concerned districts or an extrapolation with unknown error. Second, the ranking by return is close to the inverse of the ranking by area. The crops that pay best — saffron, heeng, seed potato and apple — occupy the smallest area, while the cereals that occupy most of the cultivated land return least, wheat yielding under half what the neighboring plains achieve. This explains both the shift away from food grains and the water and climate situation that creates shifting. Third, the returns in Table 3 are gross, and net income is falling across every category under rising fertiliser and labour costs, post-harvest losses of 15–20% in horticulture, transport costs from remote tracts, and inefficient distribution (Kumar, 2017; Drishti, 2024). Minimum support price covers mostly non-snowy region products: wheat, paddy, gram and masoor, at ₹ 25.85, ₹ 21.50, ₹ 58.75 and ₹ 70.00 per kg respectively as notified on 1 October 2025 for the year 2026-27, so precisely those high-value crops on which the region's prospects rest carry no price floor. Growth in income to farmers, facing investments and losses are unexplained. The cost to the consumer is roughly above double the farm-gate price, and the difference accrues to wholesale and retail trade rather than to the grower.

Out of largest District area of 13835 km^2 Lahaul-Spiti (Chandra, Bhaga and Spiti basins) in HP about 36% (4980 km^2) area is cultivable but its nearly 6 % land under foodgrain cultivation getting terrain surface snow-ice melt water, having glacier compartments nearly above 4500 m altitude. The area (ha), production (tonnes) and yield (t ha^{-1}) from 2000-01 to 2022-23 for major Rabi crops, Barely, Rapeseed/Mustard, Wheat, Pulses and Potato grown in Lahaul & Spiti district as per national records reveal (Figures1A to 1E) entry of pulses from 2005-06, covering just 769 ha in 2000-01 by first three crops and 2312 ha in 2005-06 without presence of potato and all five crops only in 2018-19 /2019-20 covers 1689 ha only.

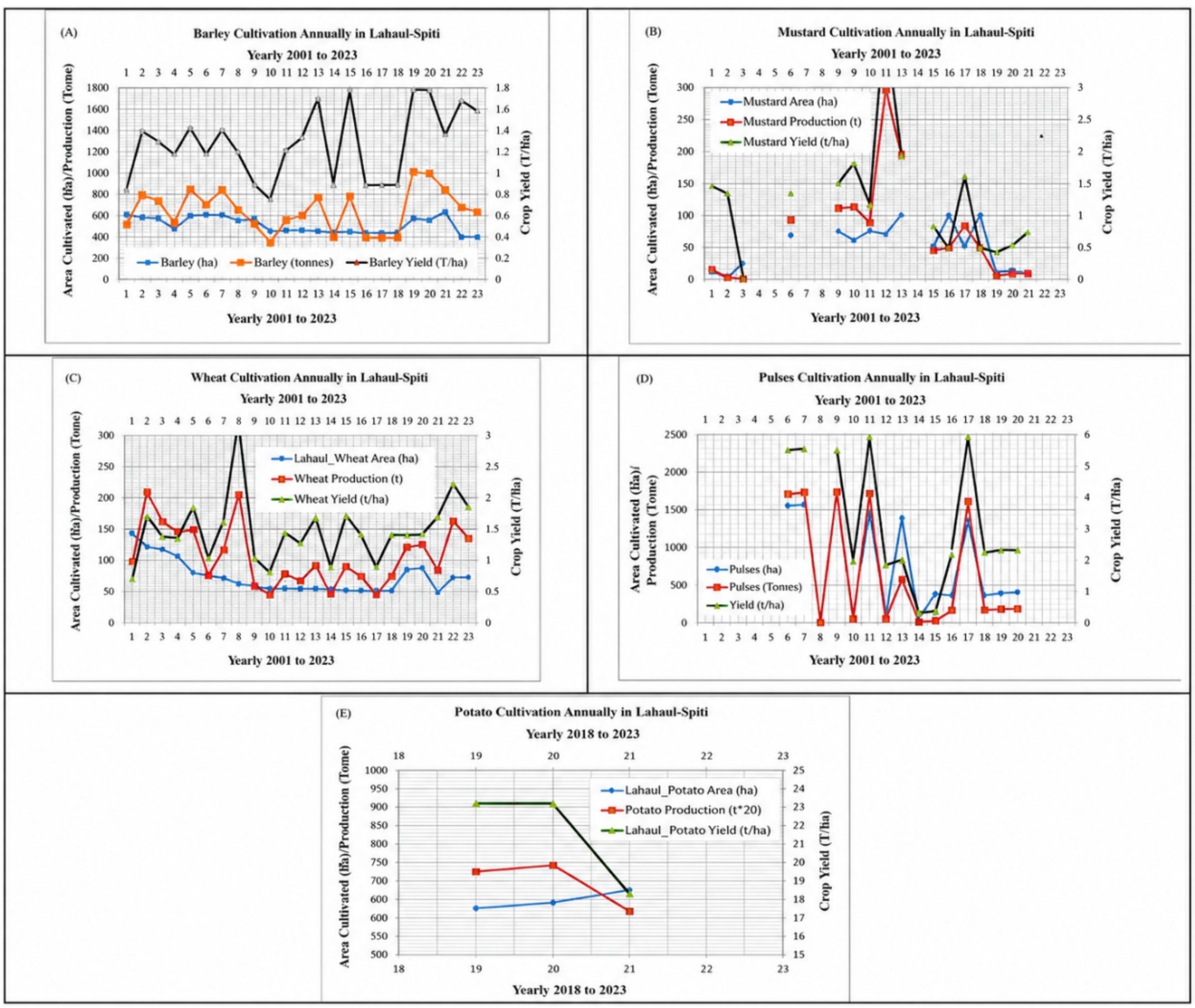

FIGURE 1 Rabi major crops area coverage, production and yield pattern and trends over two decades in Lahaul and Spiti district of HP (*Excell data, Government Statistical Portal*).

The true statistics can't be achieved with missing information but it shows evidently an interesting, clear and eye-opening trend towards farming uncertainty. The Barley crop cultivation remained consistent within 636 and 410 ha with improved yield from 1.2 t ha^{-1} to 1.8 t ha^{-1} (1.5 times) with an average of 1.27 t ha^{-1}. Mustard crop takes periodical varying from 101 ha to 3ha with yield above 3 t ha^{-1} to below 0.5 t ha^{-1} (average 1.25 t ha^{-1}) may be due to market and locals' issues. Wheat is second regular crop with decreased trend of area (142 ha to 49 ha with an average of 74 ha) and area regained since 2017while yield since 2010s from 1 to 2.3 t ha^{-1} (average 1.49 t ha^{-1}), may be due to adaptation of Natural farming and further motivation. Farmers might have been motivated towards pulse during 2010s with larger area (1574 to 6 ha, an average 791 ha) with high yield of 3t ha^{-1} (varying between 0.5 and 6 t ha^{-1}) incoherently encroaching wheat and potato. The potato cultivation area and yield remained nearly 650 ha and 22 t ha^{-1}, respectively as reported after 2018.

Overall area wise participation of Barely, Mustard, Wheat, Pulse and Potato is 24.7, 2.5, 3.5, 38.1 and 31.1 percent, respectively with an average yield of 1.27, 1.25, 1.49, 3.15 and 22 t ha^{-1}, respectively. Raghuvanshi et al. (2018a&b) surveyed under ICAR-CAZRI, Leh Programme during 2013-15 in Saboo Village of Ladakh, located within 3500 and 3745 m altitude and utilized 75 % area under vegetable compared to cereals (wheat and barley) in 25% only, where weed control alone enhanced productivity by 10 to 20%. Total energy input was highest for potato but the staple crops barley and wheat had lowest (29.2 and 25.4×10^5 kcal ha^{-1} $year^{-1}$, respectively) avoiding man, machine and labour input for weeding and considered energy efficient crops at the cost of growth in production. The energy Output/Input Ratio computed as 2.5, 3.5, 0.6, 0.3, 0.3, 0.2, 0.7 for Barley, Wheat, Tuber (Mainly Potato), Pea, Vegetables, Onion, & Alfalfa, respectively. The productivity of Barely, Wheat and Potato in Saboo Village as per table (Raghuvanshi et al., 2018) is 0.53, 0.82 and 12.9 t ha^{-1} (half of the Lahaul-Spiti), respectively but an average yield in Leh and Ladakh for Barley and Wheat is 1.94 and 2.17 t ha^{-1} (1.5 times of Lahaul-Spiti), respectively. Goyal and Gaur (2025) report that traditional technologies (zings, kuhls) increase irrigation coverage by 20-30%, while modern innovations (artificial glaciers, ice stupas, polyhouses) extend growing seasons and boost yields by 20-40%. Consequently, there are potentials for enhancement of cropping area due to early retreating snow cover and productivity with research based agro-technology development integrating with seed, weed, water, hazard, accessibility management.

3.2 | Hazards, Forest Cover and Water Resources

Challenges are due to various natural or manmade hazards as well as challenges posed by deforestation and uncertainty of sustainable water supply for irrigation and drinking purposes.

3.2.1 | Hazards Profile and recorded losses

Beyond productivity and income, the region's agriculture is shaped by hazard. The State is exposed to avalanche in the high tracts of Lahaul-Spiti and Chamba, where unstable snowpack rests on critical slopes with poor anchorage; to glacial lake outburst flood and to the risk of failure of hydropower structures; to periodic drought, aggravated by shifting rainfall and reduced snowmelt; to earthquake, the State lying in seismic Zones III and IV with 53–98.6% of the area of Chamba, Hamirpur, Kangra, Kullu and Mandi susceptible and over 80 events of magnitude 4 or above on record; and, most frequently, to landslide, cloudburst and flash flood on deforested and poorly drained slopes destabilised by unregulated road and building construction (HPSDMA, 2025; IWP, 2023; ET, 2023). Mean surface temperature has risen by about 1.6°C over the last century,

TABLE 4 Recorded disaster events and losses in Himachal Pradesh, 2020 to 2025.

Year	Recorded events	Human loss	Agricultural and livestock loss	Economic loss	Source
2020	16 landslides	Not systematically recorded	Not recorded	Not availiable	IWP, 2023
2021	35 landslides (more than double 2020); cloudbursts up 121%	75 buried in Mandi; 19 bodies recovered, 56 missing	215 animals lost; 470 families displaced; 34 bridges collapsed	Not documented statewide	Mongabay, 2021
2023	113 landslides, 58 cloudbursts, 72 flash floods; three heavy spells (7–11 Jul, 11–14 Aug, 21–23 Aug). In Kullu dist., Mandi by R.Beas	404 dead, 38 missing, 377 injured	10,140 livestock killed; 5,644 cowsheds destroyed; 2,546 houses destroyed and 10,853 damaged; 317 shops damaged	Over ₹12,000 crore; ₹50.34 crore spent from the State calamity relief fund	IWP, 2023; Kumar et al., 2025; Singh and Chand, 2023; Kumar, 2022; Rediff, 2025
2024	Floods, landslides and cloudbursts in State	408 dead — the highest of any Indian State	Not disaggregated	Not available	Manral, 2025
2025 (July to August)	Cloudbursts and flooding in Mandi and Kullu	85 dead in Mandi	Not disaggregated	Not available	News Media

and glacial retreat and earlier snowmelt now contribute to flooding in the Satluj, Vipasa and Chenab. Table 4 sets out the recorded losses of the last five years.

Two things are apparent. The frequency of recorded events has risen sharply, landslides sevenfold between 2020 and 2023, although part of that rise may reflect improved reporting rather than incidence alone, since the earlier years carry no systematic record. More important for the purposes of this review, agricultural loss is captured only where it takes the form of dead livestock or destroyed cowsheds. Damage to standing crops, to kuhls and to link roads is recurrent and cumulative but is nowhere quantified, to integrate with agricultural planning. Relief flows through the State and National Disaster Response Funds after the event, while expenditure on removing the causes — above all unregulated construction against the science, technology and natural setting — remains small or biased. The measures most consistently recommended in the literature are: (i) enforcement of zoning that prohibits construction in active sliding zones, as warned in respect of Joshimath in the 1976 Mishra Committee report (Mongabay, 2021); (ii) sector-specific strategies for agriculture, housing, health and transport to mitigate disaster rather than undifferentiated relief (Kumar *et al*., 2025); (iii) engineering and bioengineering slope stabilisation, including retaining walls and vegetative treatment (Singh and Chand, 2023); (iv) revision of District Disaster Management Plans to incorporate multi-hazard, human mentality and climate risk, with expanded training (HPMandi, n.d.; HPShimla, n.d.); and (v) strengthened meteorological, geological and hydrological monitoring, with building codes suited to mountain terrain and preservation of traditional architecture (Pandey, 2023). Involvement of agriculturists, geologists, hydrologists, government and local communities at the planning stage may ensure safety and compliance with environmental standards.

3.2.2 | Afforestation and soil erosion

The snow-receiving western Himalaya is sensitive to climate change because forest cover above 3,500 m is negligible and deforestation at lower elevations has been extensive. Tree and herbs/bushes protect climate and control soil erosion hence forest conservation requires appropriate afforestation together with climate-resilient practice — moisture-stress-tolerant tree and crop varieties and improved water management. Interesting study on tree with elevation:- Trees diversity and basal area decrease with rise in elevation due to severity of the climate but root:shoot ratio increases, as elevation increases. In Rhododendron campanulatum species attaining maximum altitude of alpine climates has ratio of 0.62 to 0.70, much deeper root in order to capture more nutrients and water from soils often frozen (Garkoti and Singh, 1995; Adhikari and Rawat, 2012). Consequently, trees and climate are interacting each other and impacting vice-versa. Root goes deeper in arid cold and warming alarms snowline to go up which indicates that sustainability of climate lies with trees conservation.

The principal gaps are inconsistent data on snow cover change, weak integration of traditional knowledge, inadequate technical and financial support to farmers, and limited community participation in conservation, particularly in raising biomass production and protecting trees from commercial felling. DEST (2025) sets out a comprehensive plan and policies integrating the concerned departments and the public for conservation of forest, ecology and the regional social economy, but implementation has yet to begin on the ground. The following steps deserve priority:

- Forest conservation is a national issue and requires close coordination between the concerned departments.
- Local communities should be informed, empowered and rewarded for conserving forest.
- Felling or timber marketing of healthy and protected trees, other than those naturally damaged or personal, should be stopped and treated as a serious offence.
- Afforestation research and plant protection programmes need continuity.
- Herbs, vegetables, flowers, fruit trees and grasslands should be regenerated.

3.2.3 | The snow-met and water resources

Sustainable water supply is critical for irrigation, drinking water and hydropower, and is being disrupted by reduced snowfall and earlier snowmelt; the corrective measures are water harvesting, micro-irrigation and climate-resilient varieties (Gupta, 2022; ET, 2025). Quantitative data on the effect of climate change on local food security in these regions are lacking. Where steep slopes and intensive cultivation accelerate erosion, agroforestry and terracing can stabilise soils (Bahadur *et al*., 2022); where warming increases pest prevalence, as with aphids and tuber moth, bio-pesticides and traditional methods give control (Verma and Vashisth, 2025; Pinto, 2018).

Snow-met seasonal average analysis at Solang Valley (2,500 m) of Kullu Dist. highlights the effect of warming since 1980s for two and half decades. Figure 2 shows seasonal (November to April) minimum temperature rising 0.032°C/yr higher than seasonal maximum temperature. Figure 3 shows annual snowfall reduced by 50%, at close to 20 cm/yr. Figure 4 shows a marked reduction in standing snow, although the average melt rate has remained uniform at 1 cm snow water equivalent (SWE) per degree-day. Figure 5 shows location specific snow cover growth and decay in 1985-86 at different altitudes 2,200, 2,500 and 3,100 m south of the Pirpanjal range and at 3,300 and 3,800 m north of it, snow cover disappearing in mid-February, end-February, mid-March, end-March and end-April, respectively. The regional changes or variability is reversible if adequate counter measures are taken against the unnatural human activities.

Ground Report Desk (2024), reporting findings of the State Centre on Climate Change, recorded an 11% fall in snow cover across the river basins in 2022-23 relative to 2021-22, the basin-wise reductions being 0.39% in the Chenab, 6.9% in the Beas, 22.42% in the Ravi and 14.61% in the Sutlej. Sediment carried by erosion, avalanche and landslide obstructs stream flow. During July-August, 1987 the Chhota Shigri glacier stream of the River Chandra, sediment transport varies between 103 and 2,040 ppm by weight or 0.2 to 1.8 g/l by concentration, at daily discharges of 7 to 12 m³/s (Figure 6; NIH, 1987). Sediment yield remains lowest during winter in avalanche free zone. Designed annual sediment yields for the Trans- and Greater Himalayan regions are estimated at 1,600 and 3,2 00 t/km² respectively, means higher reaches yield higher sediment. In avalanche- and landslide-prone reaches, anchorage, reinforcement and control structures such as rakes and snow bridges are required to limit bed load (Verdhen *et al*., 2012). Storage and hydropower structures in snow-bound terrain need particular care against avalanche run-out and icing over the spillway crest (Verdhen, 2012), and freeboard should be set by the greater of avalanche debris depth and the depth arising from wind and seismic effects. Ice conditions are themselves changing: Mladenova (2022) observed difficulty in detecting ice crusting remotely but using meteorological data Nalbant and Sharma (2022) estimated reductions of 13–35% in river ice thickness over the first half of this century and 30–57% over the second in northern USA rivers, so ice-jam flooding may decline. Transportation, logistics, settlement and rehabilitation remain the governing constraints for any such structure in sub-zero conditions.

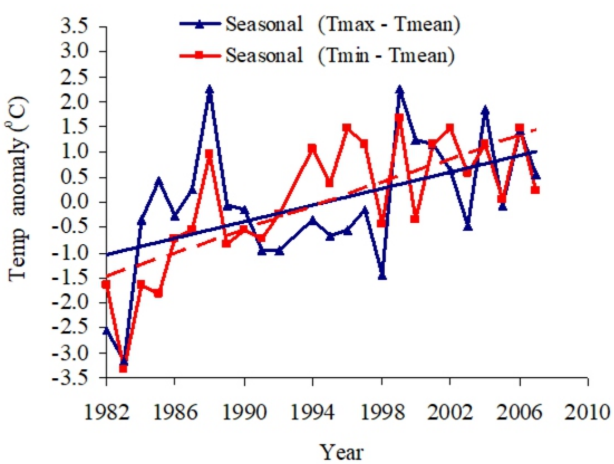

FIGURE 2 Winter season temperature anomaly during years 1982 to 2007 at Solang in southern slope of Pirpanjal range of Himachal (After Verdhen *et al.*, 2011).

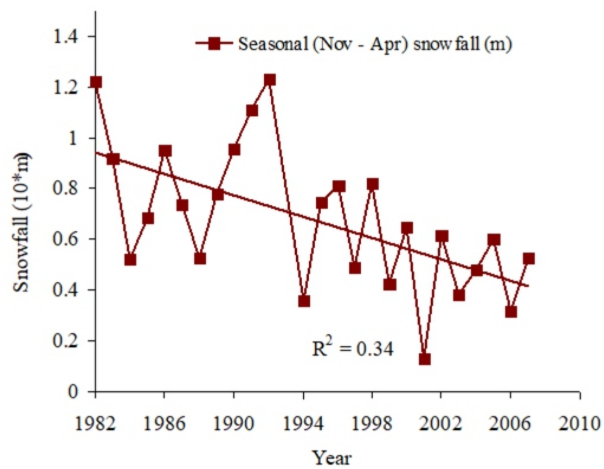

FIGURE 3 Snowfall trend in two and half decades at Solang (After Verdhen *et al.*, 2011).

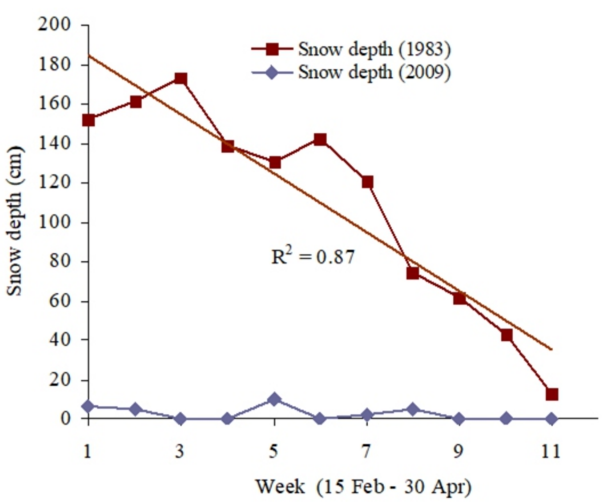

FIGURE 4 Spring snow depth weekly in 1983 and 2009 at Solang (After Verdhen *et al.*, 2011).

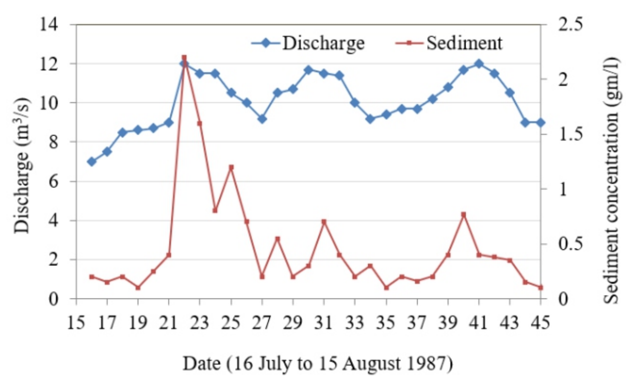

FIGURE 6 Sediment load transport with glacier melt flow through Chhota Shigri glacier of the river Chandra in Himachal Pradesh (After NIH, 1987 and Verdhen, 1991).

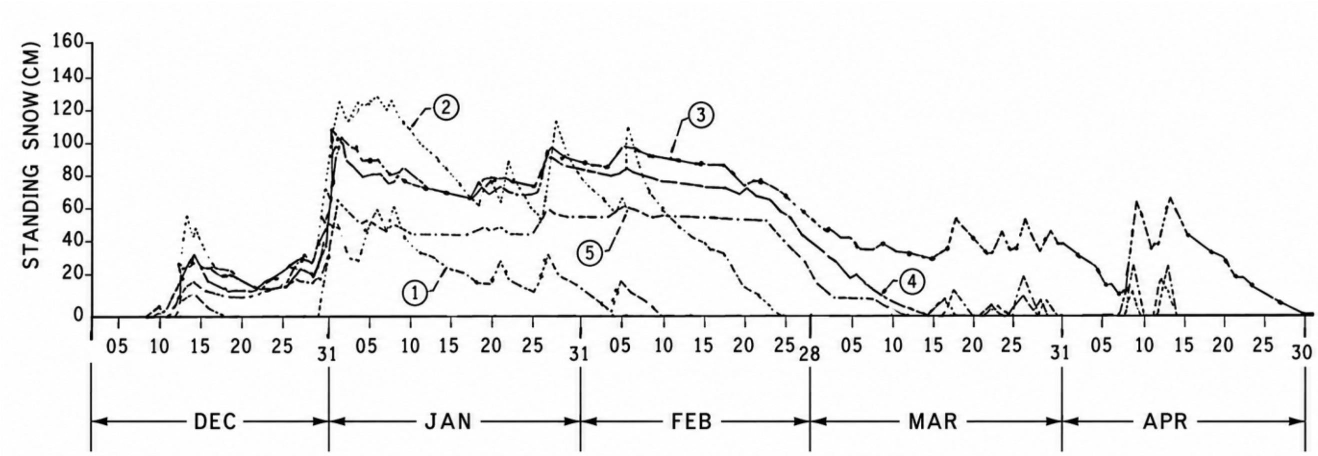

FIGURE 5 Localized snowpack growth and decay profile along Manali-Leh axis at Bhang, Solang, Dhundi, Jespa and Patseo during winter and spring of 1985-86 (After Rao *et al.*, 1987 and Verdhen, 2022).

3.2.4 | Case study: the Gypsa dam

The proposed Gyspa dam brings these constraints together in one project, and is summarized in Table 5. Cropping intensity in Lahaul and Spiti is low because of climatic constraint, water scarcity and soil erosion of about 16.4 t ha^{-1} annually, compounded by tribal economic structure and hazard exposure (Next-ias, 2024). The 2011 Census recorded Gyspa 's population at 202 in 51 households, dependent on farming and on cattle and sheep, growing barley, potato, peas, vegetables and saffron — the crops best suited to cold-tolerant, drought-resistant cultivation (Prashar, 2024). Assured water supply with micro-irrigation could raise cropping intensity by 10–15% and permit double cropping, potato reaching 25–35 t/ha, peas 20–30 t ha^{-1} and barley stabilising at 2,000–2,500 kg ha^{-1}, with a further 20–30% from polyhouses; these are projections from comparable sites, not measured local outcomes.

Gyspa lies on the Manali–Leh highway and has clear eco-tourism potential under Swadesh Darshan 2.0, which could fund water infrastructure while conserving the local ecosystem. The case nonetheless illustrates the central difficulty of this review: a scheme of this scale has been contested for more than fifteen years without an agreed baseline of hydrological, sediment and agricultural data on which either side could rely.

TABLE 5 The Gyspa dam project: salient features, claimed benefits and constraints.

Item	Description
Location and status	Keylong tehsil, Lahaul and Spiti; Gyspa valley, c. 3,200 m amsl. Designated a project of national importance (CWC, 2018); no recorded progress since 2018 and effectively in abeyance.
Structure	200 m high storage dam; 14.964 km headrace tunnel; 20 m diameter surge shaft; underground powerhouse (HPPCL, 2018).
Storage and power	0.65 million acre-feet (MAF); 300 MW installed; 894.86 million units in a 90% dependable year (HPPCL, 2018; Wiki, 2024a).
Hydrological setting	Cold desert; dry summers, long freezing winters; negligible rainfall in rain shadow; glacial and snowmelt dependent. Winter flow 100–150 m^3/s, monsoon flow 700–2,500 m^3/s.
Claimed benefits	An additional 5,000–10,000 ha irrigated; crop yields up 20–30%; flood attenuation for cropland and infrastructure in the Gyspa valley; power for irrigation pumps and polyhouses; sediment trapping downstream.
Principal risks	Seismic Zone V; tunnel-induced slope destabilisation; drying of springs; reservoir sedimentation; avalanche run-out and spillway icing; displacement and rehabilitation; disruption of traditional kuhls (Chaudhary, 2016; Verdhen, 2012; Verdhen et al., 2012; Uniyal and Rawat, 2018; Iyer, 2023)
Opposition	Opposed since 2009 by the Gyspa Bandh Sangarsh Samiti on grounds of displacement, submergence of Darcha, Sumdo and Linkyum, and loss of kuhl-based water rights; soil testing not permitted.

3.3 | Emerging Technologies and Market Access

Remote sensing, notably MODIS snow cover data, combined with suitable hydrological models can be used to estimate snowmelt flow and its timing for irrigation planning (Aparna and Shahnawaz, 2022). The need is pressing: a weekly-average temperature increase of 1.2°C over 1985–2009, the 1990s being the warmest decade, has accelerated snowmelt, disturbed irrigation schedules and dried springs; snowfall fell by 14.05% between 2021-22 and 2022-23; and the 845 glaciers of Lahaul and Spiti, some covering 100 km², are retreating at 1–2% a year, reducing flow to snowmelt-fed kuhls and raising the risk of crop failure (Sherpa, 2024). Farmers are meanwhile shifting from barley to water-intensive but more remunerative crops such as pea and cauliflower, increasing demand as supply contracts (Shashni & Sharma, 2022) — part of a longer decline in district wise crop diversification found by Mohan et al. (2025) between 1972-75 and 2012-15, as food grains gave way to fewer superior cereals and to more remunerative fruit and vegetables. Indigenous water conservation systems merit modernisation rather than replacement (Sharma & Kanwar, 2009); micro-irrigation and kuhl restoration cost ₹10,000–₹50,000/ha and are affordable at an 85% subsidy, though private investment remains limited by an average holding of 0.59 ha.

Crop monitoring technology is well established elsewhere but barely applied here. Becker-Reshef *et al.,* (2023) showed that crop calendars and crop-type maps allow crop-specific signals to be extracted from satellite data through the growing season, so that development can be tracked and yields forecast before harvest; the GEOGLAM and AMIS initiatives, launched by the G20 agriculture ministers after the food price crises of 2007/08 and 2013, provide a globally harmonised dataset for monthly crop condition assessment of wheat, maize, rice and soybean, but the Indian component has yet to be updated and monitored for Himachal Pradesh. At field scale, Nashir (2024) integrated IoT sensors and wireless networks for real-time monitoring of crop health, soil condition and environment in support of online agricultural markets, with an F1-score of 0.83, and Padhiary *et al.*, (2025) reported 85% accuracy for GIS in handling geographical data, 92% detection accuracy for remote sensing of crop and environmental condition, and a 40% reduction in workforce cost from all-terrain vehicles and automated systems using machine learning, the internet of things, targeted sensors and drones — gains that depend on collaboration, investment and training.

Securing a reliable price remains the harder problem. Remoteness impedes marketing, a constraint that warehousing, safe road connectivity and institutional support would substantially reduce; improved roads, cold storage to cut post-harvest losses and farmer-friendly institutions are therefore priorities (Sharma, 2011; Sati, 2005). Farmers should be engaged in identifying adaptation measures so that solutions are culturally appropriate and supported by agro-advisory services that provide reliable weather forecasts and pest alerts (Rana *et al*., 2021), alongside bio-pesticides and traditional pest control (Pinto, 2018). Energy demand in this cold climate is far higher than in the plains, yet above 3,000 m, forest cover is negligible, and icing and overcast snowy days limit hydro and solar generation, respectively. Development projects undertaken under such conditions require time-and-work studies, current technology, and realistic monitoring if they are to be hazard-free, sustainable, and of benefit to local people, culture, environment, and ecology.

4 | CONCLUSIONS

Agriculture in the snow-receiving Himachal mountains requires an approach tailored to the terrain, balancing economic viability against environmental sustainability. Cold-tolerant crops — barley, wheat, potato and the pseudo-cereals — alongside high-value saffron, heeng and apple, are best suited. Practices used in comparable conditions in Canada, the United States and Russia can be assessed alongside traditional knowledge to raise productivity and resilience. An inventory and assessment of the resources of the State's alpine zone, nearly 36.84% above the tree line, is needed to frame strategies and research for extending land use, selecting type of vegetation that zone can support.

Agricultural investment in snow-receiving regions flows through government schemes for erosion control, rainwater harvesting, polyhouses, and natural farming, but the reported annual rate of progress is nearly constant at the State level, casting doubt on the figures. Productivity is moderate: wheat 1.85 t ha^{-1}, vegetables 20–25 t ha^{-1}, seed potato 20–30 t ha^{-1}, and apple 8–12 t ha^{-1} in the better orchard belts against a State average of about 5.6 t ha^{-1}, all constrained by climate and soil. Returns are highest for saffron (₹5–10 lakh ha^{-1}), seed potato (₹1–2 lakh ha^{-1}), apple (₹2–4 lakh ha^{-1}) and vegetables (₹50,000–₹1 lakh ha^{-1}) over the periods covered by the sources cited, but profitability is falling under rising costs and market inefficiency. The average yield of the major crops, barely, mustard, wheat, pulse and potato in Lahaul-Spiti is 1.27, 1.25, 1.49, 3.15 and 22 t/ha, respectively.

Hazards, climate variability, water scarcity and market access must be addressed together, through policy support, research and infrastructure development. Infrastructural development has facilitated mobility but earthquakes, landslides, avalanches, floods and cloudbursts have been aggravated by local climate variability, deforestation and hurriedly unchecked construction which resulted in losses and socio-economic-cultural disruption.

The response required combines immediate relief with science- and technology-based development policy that conserves snow, soil, water, and forests, and strengthens markets, minimum support prices, transport, tradition, tourism, and the environment, to the benefit of farmers and consumers alike. The State possesses the resources for a thriving tourism sector — geographical and cultural diversity, and a clean and peaceful environment.

The Gyspa dam, with a storage capacity of 0.65 MAF, is designed to supply water and generate power and could raise crop yields in its command by 20–30%, but local opposition, in the absence of credible assurances on sustainability and rehabilitation, has left its future uncertain.

The data used here come from the Directorate of Economics and Statistics, other Himachal Pradesh government reports and published research, and are notably short of current, dynamic information for the snow-receiving higher altitudes. The region's traditions of straightforward dealing, local cooperation and the hard work of its women are its principal strength; village institutions, working with government, will be decisive in realizing its potential and conserving a fragile Himalayan ecosystem.

District and tehsil offices should observe, compile and analyse local hydro-meteorological data for planning, and share it with villagers. Growers need better advice on suitable varieties of vegetables, flowers, and fruits. Further, multidisciplinary study is needed of micro-irrigation designed to keep pipes free from icing, snow-ice melt harvesting, hazard mitigation, sheep and cattle management, climate-resilient quick-maturing crops, GIS-based erosion modelling and afforestation, and of ecotourism, if a sustainable water supply, crop productivity and economic resilience are to be secured.

ACKNOWLEDGEMENTS

The author is thankful to the Chief Editor, the editorial board and the publication team of the Indian Journal of Soil Conservation for a series of critical reviews and valuable suggestions, and to the Secretary, IASWC, Dehradun, for permitting an extension of time.

FIGURE PERMISSIONS

Figures 2, 3 and 4 are reproduced from Verdhen *et al.,* (2011); Figure 5 is after Rao *et al*., (1987) and Verdhen (2022); Figure 6 is after NIH (1987) and Verdhen (1991). Written permission / no-objection from the respective copyright holders have been obtained by the author and are available with the Editorial Office.

CONFLICT OF INTEREST

The author declares no conflict of interest.

FUNDING

This review received no specific grant from any funding agency.

DATA AVAILABILITY STATEMENT

Data can be made available on request.

AUTHOR'S CONTRIBUTION

Review, analysis, manuscript preparation, and revisions were carried out by the author. The handling editor, Chief Editor, editorial team of IJSC, and IASWC Secretary also made substantial contributions to editing the manuscript and refining its language and expression to meet the required quality standards.

REFERENCES

Adhikari, B.S., and Rawat, G.S. 2012. *Glimpses of forestry research in the Indian Himalayan region*. Chapt. 4:41-53. Edited by: G.C.S. Negi & P.P. Dhyani Published by: G.B. Pant Institute of Himalayan Environment and Development, Almora & M/s ishen Singh Mahendra Pal Singh, Dehradun.

Anand, M. 2015. *Green Growth and Agriculture in Himachal Pradesh*. Draft Final Report of Teri, DST, GoHP.

Aparna, and Shahnawaz. 2022. Spatial-temporal variations in snow cover in Himachal Pradesh, India- 2005-2015, *Geographical Analysis*, 11(1):10-17. Doi.org/10.53989/bu.ga.v11/1.22.3. Researchgate. net/publication/380848787.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.,* 8(1): 19–32. https://doi.org/10.1080/1364557032000119616.

Bahadur, K., Tzadok, E. and Pant, L. 2022, Himalayan ecosystem services and climate change driven agricultural frontiers: a scoping review. *National Institute of Health Publ Med;* pmc.ncbi.nlm.nih.gov/ articles/PMC9579111.

Balihar, R. and Dahiya, S. 2024. Enhancing agricultural sustainability through integrated weed management. *Int. J. Res. Agron.,* 7(5):87-92. DOI: https://doi.org/10.33545/2618060X.2024.v7.i5Sb.717.

Becker-Reshef, I., Barke, B., Whitcraft, A., Oliva, P., Mobley, K., Justice, C. and Sahajpal, R. 2023. Crop type maps for operational global agricultural monitoring. *Sci. Data,* 10 (172), www.nature.com https://doi.org/10.1038/s41597-023-02047-9.

Bhandari, R. 2024. Winter water woes no more: Lahaul-Spiti villages at 10000 feet plus to enjoy uninterrupted water supply. Lahaul-Spiti/Chamba. *The News Himachal;* thenewshimachal.com/2024/.

CEICdata, 2000-2023. *Agricultural Yield of Food Grains in Major States: Wheat: Himachal Pradesh.* Directorate of Economics and Statistics, Dept. of Agriculture and Farmers Welfare: ceicdata.com/en/india/.

Chandel, R.S. and *et al.* 2020. *Enabling Sustainable Food Systems Mechanism in Himachal Pradesh*. *In*: Proc. of International Workshop on the Title. State Project Implementing Unit (SPIU)-PK3Y, GoHP:1-12.

Chandel, V.B.S., Brar, K. and Kahlon, S. 2013. Land use and land cover changes in Kullu valley of Himachal Pradesh. *Int. J. Geomatics Geosci.,* 3(3):538-551. researchgate.net/ publication/32625408427.

Chaudhary, J. 2016. *Dirty Hydro in Himachal Pradesh*. Intrview with Ashar, M. of Himdhara: dialogue.earth/en/climate.

Chowdhury, A., Das, H.P. and Singh, S.S. 1993. Agroclimatic classification in India. *Mausam*, 44(1):53-60.

Deshpandey, T. 2017. *State of Agriculture in India. Analytical Reports*. PRS Legislative Research, Gandharwa Mahavidyalay, N. Delhi, pp: 1-28. prsindia.org/policy/

DEST. 2025. *Environment Policy Guidelines*. Department Of Environment, Science Technology & Climate Change Government Of Himachal Pradesh, India:1-12, https://dest.hp.gob.in/ ?q=environment-policy-guidelines.

Dhar, O.N. and Nandargi, S. 1991. A study of exceptionally heavy rainspell of September, 1988 over northwest India. *Vayu Mandal.*

Drishti, 2024. *Horticulture Sector in India-2*. News-analysis, Drishti-IAS, Delhi; drishtiias.com/daily -updates/daily-/

Eldho, T.I. 2009. Integrated watershed modeling and characterization using FEM, GIS & Remote sensing techniques. *ISH J. Hydraul. Eng.,*15(sup1):227-243. DOI: 10.1080/09715010. 2009.10514977.

ET, 2023. *Preliminary Analysis of 2023 Disaster Across Himachal Pradesh*. Environics Trust (ET); environicsindia.in.

ET, 2025. Unraveling the Himalayan conundrum: the vanishing snow and its implications in North-Western India. *The Economic Times*; indiatimes/print-article/107119531/.

Gairola, S., Rawal, R.S., and Todaria, N.P. 2025. Exploring altitudinal influences on forest vegetation patterns in the sub-alpine zone of the western Himalayas, India. *Afr. J. Agron.*, Vol. 13 (4):001-007 (*International Scholars Journals*), ISSN: 2375-1185.

Garkoti, S.C. and Singh, S.P. 1995. Variation in net primary productivity and biomass of forests in the high mountains of central Himalaya. *J.*

Veg. Sci. 3:15-20.

Goyal, R.K., Gaur, M.K., 2025.Water Management Technologies in Ladakh's Cold Arid Region : Climate Impacts and Adaptive Strategies - A Field Documentation Study. *Indian J. Soil Cons*., 53(3) (*Hill & Mountain Agriculture S*pecial Issue)**:** 204-221 DOI: 10.53550/ijsc.v53.i3.204

Gupta, V. 2022. Farming becomes tough in Himachal's cold desert with changing climate and crop pattern. *India.mongabay.com*.

H.P. 2022. *Statement Showing Season Wise Area, Production & Productivity of Principal Crops of Himachal Pradesh*. Dept. of Agriculture, H.P.; hp.gov.in/en/production-2/

Hagg, W., Braun, L.N. Weber, M., and Becht, M. 2006. Runoff modelling in glacierized Central Asian catchments for present-day and future climate. IWA Publishing, *Nordic Hydrology,* Vol 37(2):93-105.

Haldorsen, S. and Kruger, J. 1990. Till genesis and hydrogeological properties. *Nordic Hydrology,* 21:81-94.

Himachalservices, 2022-23. *Agriculture and Horticulture*. Economic & Statistics Department, Himachal Economic Survey: himachal services.nic.in/economics/ecosurvey/en-IN/

HPMandi, *Disaster Management*. District Disaster Management, Mandi. Govt. of Himachal Pradesh: hpmandi.nic.in/disaster-management.

HPPCL, 2018. *Gyspa Dam Project*. Himachal Pradesh Power Corporation Limited: hppcl.in/content/612_5.

HPSDMA, 2025. *Hazard Profile*. Himachal Pradesh State Disaster Management Authority. HP: hpsdma.nic.in/index1.

HPShimla,. Disaster *Management Training Plans.* District Disaster Management Authority, Shimla. Govt. of Himachal Pradesh: hpshimla.nic.in.

HT, 2020. Himachal to bring 4000 hectare and under red rice cultivation in 5 yrs, story. *Hindustan Times*: hindustantimes.com/indianews.

ICAR, 2016. *Himachal Pradesh*. Indian Council of Agriculture Research: *icar.org.in/nod/17266*.

IWP, 2023. How can Himachal Pradesh be protected from natural disasters. *India Water Portal*. website: indiawaterportal.org/climate-change/disasters/

Iyer, B, 2023. Let rivers flow free: the case for decommissioning dams in India. Sanctuary Nature Foundation, *Sanctuary Asia,* 43(10): sanctuarynaturefoundation.org/article/

Kanwar, H., Agrawal, G., Kumar, R. and Kumar, P. 2024. Recent advances in assessment of soil erodibility: A comprehensive review. *Indian J. Soil Cons.,* 52(3):224-232. DOI: 10.59797/ijsc.v52.i3.176.

Karun, B.M. 2021. *The Economy of District Kullu: Himachal Pradesh*. Himachal GK Book: hpgeneralstudies.com.

KSPB, 2016. *Organic Farming, Agriculture and Allied Sectors*. Economic Review, Kerala State Planning Board: spb.kerala.gov.in/economic-review/

Kulkarni, A.V. 1991. Glacier inventory in Himachal Pradesh using satellite images. *J. Indian Soc. Remote Sens.,* Vol. 19(3).

Kumar, A. 2017. *Economy of Growing Vegetables and Farm Incomes in Himachal Pradesh*. Book on Agriculture Situation in India, LXXIII: 23-29: researchgate.net/publication/316657788.

Kumar, A. and Ramesh, 2018. *Status*. Institute of Himalayan Bio-resource Technology, CSIR, Palampur.

Kumar, M., Gupta, T. and Baghel, V. 2025. Multisectoral impacts of the 2023 disasters in Himachal Pradesh and mitigation plans. *Infrastructure Asset Management*:1-25. Doi.10.1680/jinam-24.00025: researchgate.net/publication/390923935 .

Kumar, V. 2022. Floods and flash floods in Himachal Pradesh- mini review. *J. Geogr. Nat. Disasters,* 12(3):1-6: longdom.org/open-access/

Kumari, P., Kaler, N.S., Sharma, P., Sharma, S.D., Sharma, A., Negi, C. and Kumar, R. 2024. Dhaka agroforestry systems vis-a-vis socio-economic dynamics of the farmers: A case study of Baijnath tehsil, Himachal Pradesh. *Indian J. Soil Cons*., 52(3):249-260. https://ijsc.iaswc.com/index.php/ijsc/issue/archive DOI:0.59797/ijsc.v52.i3.179.

Kumbhar, P.S. and Rastogi, R.A. 1992. Determination of peak runoff rates from a Himalayan watershed. *Indian J. Soil Cons.,* 21(3):53-59.

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). *Scoping studies: Advancing the methodology*. Implementation Science, 5, Article 69. https://doi.org/10.1186/1748-5908-5-69.

Loukas, A. and Quick, MC. 1993. Rain distribution in a mountainous watershed. *Nordic Hydrology,* 24:225-242.

Manral, M.S. 2025. Natural disasters killed nearly 3000 in 2024: Himachal worst hit with 408 deaths. *Indian Express*, Delhi: indianexpress .com/article/india.

Mapfumo, E., Chanasykb, D.S., Puurveenb, D., Eltona, S. and Acharya, S. 2025. Historic climate change trends and impacts on crop yields in key agricultural areas of the Prairie Provinces in Canada: a literature review. *Can. J. Plant Sci.*,www.cdnsciencepub.com.

Maurya, S.K., Singh, V., Chand, K., and Mishra, P.K. 2024. Assessment of soil erosion in the Beas Valley, Kullu, Himachal Pradesh: A study of Western Himalayan landscape, Northern India. *Soil Sci. Annu.,*75(1), 185558:1-12. https://doi.org/10.37501/soilsa/185558

Meena, H.M., Manjunatha, B.L., Raghuvanshi, M.S., Verma, Archana, Angchokc, Dorjey, A., Ngawang, D., and Spalbar, E. 2023. Weather prediction using traditional knowledge in cold arid high-altitude region of Ladakh in India. *Indian J. Tradit. Knowl.,*Vol 22(4): 864-873. DOI: 10.56042/ijtk. v22i4.

Mladenova, I. 2022. *Foreign Agricultural Service*. Global Market Analysis of International Production Assessment Division, Commodity Intelligence Report (CIR), United States Department of Agriculture. Web: https://ipad.fas.usda.gov.

Mohan, P., Thakur, B.R., Devi, G. and Chand, P. 2025. Diversification of crops in Himachal Pradesh: A geographical analysis. Trans. Inst. Indian Geographers ISSN 0970-9851*, Transactions,* 47(1):147-160l

Mongabay, 2021. Himachal Pradesh and its recurring face off with disasters. *india.mongabay.com*.

MTD, 2022. *Farmer Guides an Introduction: Himachal Pradesh*. Mechanization and Technology Dept., Agriculture and Farmers Welfare, MoAFW: *farmech.dac.gov.in.*

Nalbant, M.A. and Sharma, S. 2022. Investigating the impact of climate change on river ice thickness across the Northern belt of United States, *ISH J. Hydraul. Eng.*; DOI: 10.1080/ 09715010.2022.2050309

Nashir, A. 2024. Sensor deployed agricultural land for e-commerce platform with clustering of nodes in the network. *J Sensors IoT & Health Sciences,* ISSN:2584-2560, Vol. 2(3):13-21.

Next-ias, 2024. *Cropping Intensity: Meaning-Methods-Spatial-Pattern & More*. Indian Geography: *NEXT IAS blog*.

NIH, 1987. *Chhota Shigri Glacier Expedition and Hydrological St*udies. Glacier Expedition, Dept. of S&T and NIH Roorkee, Govt. of India.

Nijampurkar, V.N., Sarin, M.M., and Rao, D.K. 1993. Chemical composition of snow and ice from Chhota Shigri glacier, Central Himalaya. *J. Hydrol.,* 151:19-34.

NITI, 2022. *Himachal Pradesh: Natural Farming: NITI Initiative*. NITI Aayog, Delhi.

Notarnicola, C. 2024. Snow cover phenology dataset over global mountain regions from 2000 to 2023. *Data in Brief 56 (2024),* Elsevier Inc. https://doi.org/10.1016/j.dib.2024.110860,(http://creativecommons .org/licenses/by/4.0/).

Padhiary, M., Saikia, P., Roy, P, *et al*. 2025. A review on advancing agricultural efficiency through Geographic Information Systems, Remote Sensing, and Automated Systems. *Cureus J. Eng., 2*: DOI: https://doi.org/10.7759/s44388-024-00559-7.

Pandey, S. 2023. Development projects in Himachal Pradesh have ignored the states geography and built heritage. *Frontline Website*: frontline.thehindu.com/environment.

Pinto, A. 2018. Climate change impacts agriculture in the northern Himalayas. Mongabay, pp1-12: *india.mongabay.com*Poudel, K., Basnet, K. and Sherchan, B. 2021. Hydrological and hydraulic modeling for flood analysis: a case study for Modi catchment. *Int. J. Eng. Res. Technol., (IJERT),* ISSN: 2278-0181, Vol. 10 (08):534-544: https://www.ijert.org

Prashar, R. 2024. Himachal cloudbursts: are hydropower projects to blame? *Climate Change, Down to Earth*, CES, Delhi; downtoearth. org.in/amp/story/climatechange.

Raghuvanshi, M.S., Dorjay, N., Singh, R.K., Manjunatha, B.L., Moharana, P.C., Enoch, S., Landol, S., and Saxena, A. 2019. Ladakh traditional farming: an approach to resource utilization under changing climate. *Int. J. Curr. Microbiol. App. Sci*. 8(09): 654-666.

Raghuvanshi, M.S., Tewari, J.C., Dolma, R., Arunachalam, A., and Om Prakash Yadav, O.P. 2018a. Struggle from subsistence to sustainability and threat to local biodiversity under changing climate: a case study on Ladakh folk agriculture. *Clim. Change Environ. Sustain,*. 5(1):59-65.

Raghuvanshi, M.S., Tewari, J.C., Pareek, K., Landol,S., Raza,M., Stanzin, J. 2018b. Energy budget of crops and weed management to enhance crop productivity in cold arid Ladakh region. *Def. Life Sci. J.*, 3(2):157-161.

Raghuvanshi, M.S**.,** Sawal, R.K., Landol, S., Dorje, N., Pandey, L., Enoch, S., Raza, M. and Saxena, A. 2023. Invasive common reed (*Phragmites australis*): A serious ecological threat to Ladakh Tethys Himalayan biodiversity in changing climate. *Am. J. Clim. Change,* 12, 321-334. https://doi.org/10.4236/ajcc.2023.123015.

Rana, R.S., Kalia, V., Singh, S., Randhawa, S.S., Chauhan, R. Katoch, A., Sandal, A., Thakur, R.R. and Upadhyay, S.K. 2021. Climate vulnerability assessment of farming systems in Himachal Pradesh, *Indian Himalayas. Mt. Res. Dev.,* 41(4):850-860. Doi.org/10.1659/ MRD-JOURNAL-D-20-00056.1. Bioone.org.

Rango, A. 1992. Worldwide testing of the snowmelt runoff model with applications for predicting the effects of climate change. *Nordic Hydrology,* 23:155-172.

Rao, N.M., Bandopadhya, B.K., and Verdhen, A. 1989. Snow hydrology studies in the Beas basin for developing snowmelt runoff model. *J. Inst. Eng. (I)*, Vol. 72, Part CV3:92-102.

Rao, N.M., Rangachary, N., Kumar, V. and Verdhan, A. 1987. Some aspects of snow cover development and avalanche formation in the Indian Himalaya. *In:* Proc. of Symposium on Avalanche Formation, Movement and Effects, *IAHS Publ*. No. 162:453-462; https://iahs.info/uploads/dms/6846.453-462-162-Rao.pdf.

Rawan, 2017. *Agriculture in Himachal Pradesh*. Himachal Pradesh Public Service Commission Note, *PSCnotes*.

Rediff, 2025. Himachal floods 4 areas worst affected 85 dead so far. *News Rediff*; rediff.com/news/commentary/2025/jul/10.

Sati, V.S. 2005. Systems of agriculture farming in the Uttaranchal Himalaya, India. *J. Mt. Sci.,* 2(1):76-85.

Sharma, H.R. 2011. Crop diversification in Himachal Pradesh: patterns, determinants and challenges. *Indian J. Agric. Econ.,* 66(1):97-114.

Sharma. N. and Kanwar, P. 2009. Indigenous water conservation systems-a rich tradition of rural Himachal Pradesh. *Indian J. Tradit. Knowl.,* 8(4):510-513; *researchgate.net/publication/ 295696586*.

Shashni, A. and Sharma, S. 2022. *S*ustainable Agriculture in a Cold Desert: Case Study of Lahaul Spiti District of Himachal Pradesh. Chapter In: *Sustainable Water Resources Management, Proc. of SWARM* 2020:228-235; researchgate.net/publication/367665208*.*

Sherpa, D. 2024. *Environmental Shifts and Dwindling Agricultural Sustainability: A Review of Lahaul-Spiti District*. Centre of Excellence for Himalayan Studies, Shiv Nadar Institution of Eminence. Issue Brief. No.6. June. 1-7; snu.edu.in/centres/

Singh, D.K. and Sarkar, T.K. 1994. Soil conservation programs and policies in India. *Indian J. Soil Cons.,* 22(1-2):290-296.

Singh, R.K. and Chand, D. 2023. Unveiling the catastrophe: disasters in Himachal Pradesh with a focus on Kullu district. *Int. J. Environ. Sci.,* 12(4):74-79; researchgate.net/publication/ 377272355*.*

Singh, R.K., Moharana, P.C., Goyal, R.K., Bhatt, R.K., Raghuvanshi, M.S., and Meena, H.M. 2019. Soil erosion- status, causes and preventive measures in Trans-Himalayan region at Leh-Ladakh of J&K. *J. Soil Water Conserv.,* 18(3):235-240.

Thaipliyal, V. and Kulshrestha, S.M. 1991. Climate change and trends over India. *Mausam*, 42(4):333-338.

Thakur, Jagriti., Kumar, Pradeep., Mohit, and Dhindsa, Kaur, and Ravneet., 2019. Influence of integrated nutrient management (INM) on soil physicochemical properties and nutrient uptake of cauliflower (Brassica oleracea var.botrytis L.). *Indian J. Soil Cons.,* 47(1): 74-80*.*

Uniyal, A. and Rawat, G.S. 2018. What is the future of water governance in the Himalayas: engage EPW, *Economic & Political WEEKLY,* 53(35); epw.in/engage/article/

Uzoagba, C., Bello, A., Kadivar, M., *et al.* 2024. Bioenergy potential assessment of crop residue biomass resources in Africa towards circular economy. *Cureus J. Eng.,* 1: es44388-024-00112-6. DOI: https://doi.org/10.7759/s44388-024-00112-6.

Verdhen, A. 1991. Hydrological study in a glaciated mountain stream. *In: Proc. of the National Meet on Himalayan Glaciology*, Meet held at DST, New Delhi, pp 33-38.

Verdhen, A. 2012. Planning design construction and operational problems of dams and spillway in the Himalayan region. *In: Proc. BIS National Seminar on Dams and Spillways in Himalayan Regions*, Bureau of Indian Standards (WR), New Delhi, India.

Verdhen, A. 2022. Localized snowpack growth densification including creep and ablation.

Online in *3rd International Conference on Snow Hydrology* (SnowHydro22), 1-4 Feb 2022 at Grenoble (France).

Verdhen, A., Chahar, B.R. and Sharma, O.P. 2011. Climate change impact on snow and ice melt runoff in Himalayan watershed. *In: Proc. 4th International Perspective on Water and Environment,* NU Singapore, IPWE 2011, 4-6 January, EWRI, ASCE, Singapore, paper no. 00152:1-10.

Verdhen, A., Chahar, B.R. and Sharma, O.P. 2012. Suspended load yield in glaciated streams in the Himalayas. *In: Proc. BIS National Seminar on Suspended Sediments for Dams in Himalayan Regions*, Bureau of Indian Standards (WR), New Delhi, India.

Verdhen, A., Chahar, B.R., and Sharma, O.P. 2013. Snowmelt runoff simulation using HEC-HMS in a Himalayan watershed. *In: Proc. of World Environmental & Water Resources Congress* 2013, EWRI of ASCE, May, Ohio.

Verdhen, A., Chahar, B.R., Ganju, A., and Sharma, O.P. 2015. Modeling snowline altitudes in the Himalayan Watershed. *J. Hydrol. Eng.,* ASCE; DOI: 10.1061/(ASCE)HE. 1943-5584.0001255.

Verma, S. and Vashisth, S. 2025. *Blending Traditional Knowledge of Farmers in Agriculture with Modern Scientific Technologies in Cold Desert Region of Himachal Pradesh.* Chapter *In:* Blending Indian Farmers Traditional Knowledge in Agriculture with Modern Scientific Technologies. Springer, 219-240. Chapter/10.1007/978-981-96-1020-4/10.

Wiki, 2007. *Economy of Himachal Pradesh*. wikipedia.org.

Wiki, 2024. *Hydroelectric Power in Himachal Pradesh*. wikipedia.org

Yangchan, J., M.S. Raghuvanshi, M.S., Kumar, A. and Arya C.K. 2019. Climate change-induced impact on water resource of Ladakh cold arid region. *Int.J.Curr.Microbiol.App.Sci* 8(5):1996-2009.

How to cite this article: Verdhen, A., 2026. Crop Productivity and Sustainable Agricultural Systems in Snow-Receiving Hazardous Himachal Mountains *Indian J. Soil Cons*., 54(2): 197-213.

Indian Association of Soil and Water Conservationists

218, Kaulagarh Road, Dehradun - 248195, Uttarakhand

Dear Life Members of IASWC,

We express our sincere thanks to you all for active support to IASWC in various ways and means. We are requesting all the members to update their profile in the format given below and also available at our website: www.iaswc.com. Dully filled in format may kindly be forwarded to the following E-mail Id: secretary@iaswc.com. **If you are not able to recall your life membership number, please leave blank and fill rest of the details.** We are also requesting you to inform your friends who are life members of the IASWC for updating their profile.

Your kind co-operation in this regard is requested, and thanks for sparing your valuable time for updating your profile.

Format for Updating Profile of IASWC Life Members

LM No.	Name	Designation	State	Address with PIN/ZIP code		Phone with ISD/STD code		Mobile	E-mail	Date of getting membership
				Permanent	Mailing/Office	Office	Residence			
1	2	3	4	5	6	7	8	9	10	11

For further details and clarifications, please contact:

Dr Raman Jeet Singh
Secretary,
Indian Association of Soil and Water Conservationists,
ICAR-IISWC, 218, Kaulagarh Road,
Dehradun - 248 195, Uttarakhand.
Mobile : 09412019784 / Fax : 0135-2754213
Website : www.iaswc.com / E-mail : secretary@iaswc.com

MEMBERSHIP AND JOURNAL SUBSCRIPTION

(W.E.F. January 01, 2017)

Subscription type	India (₹)	Foreign (US $)
Individuals		
Annual	500	100
Life	5000	600
Libraries and Institutions		
Annual	1500	200
10 years	12000	2000