NITI Aayog

COMPENDIUM ON

‘ALL WEATHER TAP WATER SUPPLY IN THE HIGHER REACHES OF THE HIMALAYAS’

August, 2025

National Institute for Transforming India (NITI) Aayog

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This compendium is the result of a collaborative effort involving numerous individuals and institutions dedicated to addressing the challenges of water access in the Himalayan region. We are grateful to the various State Government departments, academic institutions, and civil society organisations whose participation and insights greatly enriched the discussions and helped shape the outcomes presented in this document.

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Message

Access to clean drinking water is not only a fundamental human necessity, but also a critical determinant of public health, social equity, and economic development. The higher Himalayan regions, however, require specially designed water supply strategies that are resilient, sustainable, and sensitive to the unique topography, climatic conditions, and cultural contexts, to ensure ease of living, health, and dignity for rural communities, particularly women and children.

Due to challenges such as harsh climatic conditions, unique topography, and technical issues, it is still a significant challenge to provide all-weather functional tap water supply to household in the higher reaches of the Himalayas.

This compendium brings together emerging insights, promising practices, and successful models, for example, a bottom-up approach implemented in Ladakh, which demonstrates technological innovations, community participation, and context-driven planning in achieving round the year water security.

I have a firm belief that the integration of local knowledge, technical expertise, innovation and public participation is critical for providing a functional tap water supply of adequate quantity and appropriate quality in these difficult areas. I hope this Compendium inspires collaborative action, further research, and scalable solutions that make "Har Ghar Jal" a reality in every Himalayan household, regardless of altitude or adversity.

(Vinod Paul)

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FOREWORD

Providing a functional tap water supply to every household in the higher reaches of the mountains remains a challenge, and is made further difficult by high altitude and harsh climate conditions.

This document compiles the best practices, community-led innovations, technical advancements, and policy recommendations to address the important issue of providing a round-the-clock water supply to such difficult terrains. From freeze-proof pipelines and spring rejuvenation to AI-powered monitoring, the solutions showcased here reflect the convergence of traditional wisdom and modern technology.

I compliment the Water & Land Resources Division for bringing out this compendium, and I hope it will be useful for people working in water supply areas in mountainous regions.

12/9

[B.V.R. Subrahmanyam]

Dated: 12th September, 2025

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Preface

The higher reaches of the Himalayas present a unique paradox: abundant in snow, glaciers, and springs, yet facing acute challenges in ensuring access to a safe tap water supply. Harsh winters, rugged topography, remote settlements, and fragile ecosystems collectively demand solutions that are not only technically sound but also deeply rooted in local realities.

This compendium on "All-Weather Tap Water Supply in Higher Reaches of the Himalayas" is an outcome of a workshop organised by the NITI Aayog in Shimla, Himachal Pradesh, in October 2024. It brings together the diverse voices of policymakers, engineers, scientists, and community champions who are actively shaping water resilience in India's mountain states. The document is not just a record of technical approaches; it is a repository of lived experiences, hard-earned lessons, and promising models that are reshaping water security in the most challenging geographies of the country.

I appreciate the efforts put in by Ms. Shipra Singh and Ms. Iffat A Parveen, Young Professionals working under the Water and Land Resources Division, for coordinating with various contributors and collating the information and the photographs.

I hope people working in the water sector, especially in the higher reaches of the Himalayas, will find this Compendium useful.

[Yugal Joshi]

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List of Abbreviations

Abbreviation	Description
ADE	Advection-Dispersion Equation
AGV	Automated Guided Vehicles
AI	Artificial Intelligence
ANM	Auxiliary Nurse Midwife
CGWB	Central Ground Water Board
CHIRAG	Central Himalayan Rural Action Group
CWR	Clean Water Reservoir
CWRM	Composite Water Resource Management Plan
DoLR	Department of Land Resources
DoWR, RD&GR	Department of Water Resources, River Development, and Ganga Rejuvenation
DPR	Detailed Project Report
DTR	Detailed Technical Report
FTK	Field Testing Kit
G.B. Pant NHIE	Govind Ballabh Pant National Institute of Himalayan Environment
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GIS	Geographic Information System
GPR	Ground Penetrating Radar
GSR	Ground Storage Reservoir
HDPE	High-Density Polyethylene
HESA	Health Education and Social Action
IHR	Indian Himalayan Region
IoT	Internet of Things
JJM	Jal Jeevan Mission
JSD	Jal Shakti Department
LiDAR	Light Detection and Ranging
MDPE	Medium-Density Polyethylene
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MI	Minor Irrigation

ML	Machine Learning
MMI	Major and Medium Irrigation
MoJS	Ministry of Jal Shakti
NCM	Non-Contact Magnetometry
NIH Roorkee	National Institute of Hydrology, Roorkee
NRDWP	National Rural Drinking Water Programme
OHT	Overhead Tank
PHED	Public Health Engineering Department
PFR	Pre-Feasibility Report
PIPAL	People for Integrated Planning and Adaptable Living
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PRA	Participatory Rural Appraisal
PRI	Panchayati Raj Institution
PSI	People's Science Institute
PVC	Poly Vinyl Chloride
PWSS	Piped Water Supply Scheme
R&D	Research and Development
RDD	Rural Development Department
RSFP	Rapid Sand Filter Plant
SAR	Synthetic Aperture Radar
SARAR	Self-Esteem, Resourcefulness, Action, and Responsibility
SBCC	Social Behavioural Change Communication
SBM	Swachh Bharat Mission
SDG	Sustainable Development Goal
SHG	Self Help Group
SSFP	Slow Sand Filter Plant
UNWA	United Nations for Water Africa
VMW	Village Management Worker
UWSSC	User Water Sanitation Sub-Committee
WASCA-II	Water Security and Climate Adaptation in Rural India-II
WDC	Watershed Development Component
WUG	Water User Group

Executive Summary

India's Himalayan Region, home to a significant share of the nation's critical water sources, glaciers, springs, and rivers, faces acute challenges arising from climate change. Despite the remarkable progress of Jal Jeevan Mission (JJM), which has increased rural household tap water coverage from 17% in August 2019 to 80.8% in June 2025, the higher reaches of the Himalayas continue to suffer from lesser water availability due to seasonal disruptions. Water supply in the higher reaches of the Himalayas often suffers from frozen pipes, burst pipelines, and water pipe leakages. These conditions not only affect drinking water security but also place a disproportionate burden on the community, limiting their time for education and economic activities.

The *Compendium on All Weather Tap Water supply in the higher reaches of the Himalayas* highlights how innovative, context-specific solutions are emerging to tackle these unique challenges. The Ladakh model, for example, demonstrates the use of frost-resistant high-density polyethylene (HDPE) pipes buried below frost lines, insulation of exposed pipelines, and solar-powered pumping systems. These measures have proven effective in maintaining a functional tap water supply even in temperatures dropping below –20°C and at altitudes above 13,000 feet. Such localised adaptations have proved how technical expertise can overcome extreme weather challenges.

A major theme explored in the compendium is the significance of springshed management. Springs sustain more than 60% of rural households in the Himalayan region, yet rapid urbanisation, climate change, and deforestation have led to many springs getting depleted. To combat these issues, initiatives such as the National Census of Springs and integration of springshed management into watershed programmes under WDC-PMKSY 2.0 represent significant policy advancements to ensure source sustainability. The Compendium highlights successful models for systematic mapping, protection, and rejuvenation of springsheds.

The document further showcases how blending traditional knowledge with modern technology offers viable pathways for sustainable water management in fragile mountain systems. Examples from the cold desert region of Lahaul Valley reveal how traditional community-built irrigation channels, glacier ponds, and snow harvesting can be revitalised and integrated with hydrogeological assessments, remote sensing, and monitoring to enhance groundwater recharge and support local water security. Such approaches strengthen climate resilience while preserving cultural heritage.

Digitised solutions for improved water supply include the application of Artificial Intelligence (AI), Machine Learning (ML), drones, satellite-based monitoring, and Internet of Things (IoT) networks for real-time data collection and pipeline monitoring. The Compendium highlights in detail how ground sensors, drone-based sampling, and predictive analytics can enable early detection of leaks, contamination, and stress points in remote pipelines, improving operational efficiency and water quality assurance in difficult terrain.

Community-driven models form the backbone of successful implementation. Case studies from the different civil society organisations demonstrate how decentralised, small-scale drinking water schemes, supported by local user committees and extensive capacity building, have provided reliable tap water connections to households in isolated villages otherwise vulnerable to drying springs and increased water insecurity. These experiences highlight the effectiveness of participatory planning, source sustainability measures, and continuous community stewardship.

The compendium also recognises the role of state governments, local institutions, and development partners in scaling these solutions. The documented experiences from the States/UTs of Jammu and Kashmir, Himachal Pradesh, Assam, and Ladakh offer practical insights into designing all-weather water supply systems that combine technical solutions, renewable energy, insulation techniques, and community ownership.

For an effective water supply, the Compendium calls for a multi-pronged approach, robust climate-adaptive infrastructure, integrated source sustainability, real-time data-driven management, digital integration, and strong community involvement. It emphasises the need for coordinated knowledge-sharing platforms, standardised policies, and community involvement to replicate and scale successful models across the Himalayan region.

Overall, the *Compendium on All Weather Tap Water Supply in the Higher Reaches of the Himalayas* serves as a resource for policymakers, engineers, development practitioners, and community leaders working towards the vision of 'Har Ghar Jal'. By documenting challenges, solutions, and best practices, the compendium aims to carve an actionable pathway for achieving resilient and water supply security, contributing to broader goals of public health, gender equality, sustainable livelihoods, and climate adaptation for Himalayan communities.

1. Springshed Management for Water Security in the Himalayas

Dr. Sumit Sen and Dr. Bhargava Dass
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1.1 Background and Importance of Springshed Management

Springs are a fundamental water source in the Indian Himalayan Region (IHR), sustaining over 60% of rural households. These naturally occurring groundwater outlets are crucial to local water supply systems as one in every five villages has access to springs [1]; one in four surface water irrigation systems relies on spring-fed channels for surface flow irrigation [2]; and three out of five hill residents depend on spring water for their daily domestic needs [3]. However, the IHR faces unique challenges. These include extreme climate variability, harsh winter conditions, and inaccessibility, which disrupt reliable water access and strain available resources. With declining freshwater availability posing an increasing threat to water security, springshed management emerges as a vital strategy to protect these sources. Springshed management supports sustainable water supply for communities and aligns with the NITI Aayog's goal of ensuring all-weather tap water supply in Himalayas.

Free flowing spring, Instrumented Spring, Auto weather station and Rain isotope Sampler at Springsheds in Uttarakhand, India (L-R)

1.2 Understanding Springs and Springsheds

Springs can be harnessed to ensure water security in the IHR, but this requires a systematic approach that includes:

1.2.1 **Characterising the Discharge Rate and Yield**: The yeild of a spring, a fundamental property for water supply planning, refers to the volume of water a spring can reliably produce. Yield is typically expressed in terms of flow rate (or discharge rate) and the consistency of its output, which may be either perennial or intermittent. Understanding this yield is essential for determining the spring's reliability.

1.2.2 **Topographical Assessment:** Studying the topography is necessary for planning effective distribution systems.

1.2.3 **Demand Assessment:** Evaluating the demand for freshwater resources in target habitations helps guide sustainable water supply development.

Springs vary widely in yield and water quality based on geological factors, with yield depending on the groundwater-bearing layers and local hydrogeology. Characterising springs through hydrogeological mapping helps identify these layers. It's also essential to view the area of interest through a springshed definition, which considers more than one watershed and aquifer feeding a system of springs. This integrated perspective supports sustainable, reliable water supply for communities dependent on multiple springs.

1.3 Challenges and Opportunities in Springshed Development

Springs are underutilised water resource in the IHR, offering significant potential amid notable challenges. While springs serve as vital sources for drinking and irrigation, the remote locations of many springs complicate their enumeration, leading to data gaps that hinder effective resource management. Additionally, the absence of a structured classification system limits the ability to cluster springs for water supply planning thereby reducing efficiency in resource deployment. The dispersed and often inaccessible locations of many springs further complicate logistical planning and integration into local water systems. Moreover, variable water quality across different springs challenges their reliability as safe drinking sources.

All of these challenges are opportunities for springshed management. The 1st Census of Springs, proposed by the Department of Water Resources, River Development, and Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti (MoJS), is a step in the right direction. By systematically enumerating springs, authorities can identify and assess springs to determine which sources are viable and ready for use. Classification of springs, based on factors such as discharge rate, water quality, and seasonality, further enables effective planning for water supply schemes tailored to local needs. Geo-location, supported by GIS and digital interfaces, allows for the precise mapping and clustering of springs, which optimises water distribution and accessibility across regions. Additionally, ongoing testing and monitoring of water quality ensure that springs meet health standards, building community trust in the reliability of these vital water sources.

With these targeted key focus areas, systematic identification, classification, advanced geo-location tools, and consistent quality monitoring, springs can prove to become a more reliable and sustainable resource, supporting the region's water security and enhancing resilience in local communities.

1.4 Springshed Management Approach

Springshed management offers a holistic solution for addressing water scarcity challenges by combining community engagement with advanced hydrological techniques. Community involvement is essential, as residents actively participate in identifying, mapping, and monitoring springs, fostering a sense of stewardship. Protecting and delineating recharge zones further supports sustainable spring flow, while data-driven hydrology, such as real-time monitoring and modeling, provides insights into recharge and discharge dynamics, enabling informed water resource decisions.

Key factors to consider before developing a spring include assessing its discharge rate and permanency, analysing the surrounding topography for optimal pipeline layout, and evaluating local demand for water. To ensure long-term sustainability, springshed

management emphasises restoring springs, enhancing groundwater recharge, and implementing soil and water conservation practices for co-benefits. Additionally, supporting biodiversity within springsheds contributes to resilient ecosystems. Through these measures, springshed management not only bolsters water security and agricultural productivity but also fosters sustainable development across Himalayan communities.

1.5 Proposed Technological and Policy Solutions

To align with the workshop's objectives of achieving reliable, year-round water supply in the challenging Himalayan terrain, the Springshed management approach integrates several strategic interventions that leverage both technological innovation and policy development:

1.5.1 **Developing Springwater Distribution Network:** Designing, upgrading and improving existing distribution systems to the unique demands of the region can reduce loss and improve access, in remote and high-altitude areas. This includes designing efficient distribution infrastructure, use of weather-resistant materials, and green-powered pumping to ensure continuous flow.

1.5.2 **Comprehensive Water Accounting:** Implementing a robust water accounting system enables precise measurement of water inputs, outputs, and consumption across regions, ensuring efficient management of available resources. This approach also aids in identifying supply gaps and future demands and optimising water allocation.

1.5.3 **Aquifer Recharge Framework:** Establishing an evidence-based framework for aquifer recharge is essential to improve groundwater retention, infiltration, and storage. Scoping strategic interventions, rooted in hydrological science, to address the specific topographic and climatic needs of the aquifers is important.

1.5.4 **IoT and Sensor-Based Monitoring Systems:** Deploying IoT-enabled sensors for real-time data collection on water quality, flow rate, and supply levels can greatly enhance transparency and operational efficiency. These systems provide timely alerts on potential disruptions, support preventive maintenance, and help authorities make informed decisions.

1.5.5 **Coordinated Policy and Knowledge Sharing:** Establishing a cohesive policy framework is crucial for standardising springshed management practices across the IHR states. The creation of a Centre of Excellence for Springs could provide a dedicated platform for research, training, and practical implementation of springshed conservation. Such a centre would support data exchange, cross-state collaboration, and policy alignment to reinforce water security and build resilient ecosystems in the Himalayas.

Through such strategic measures, Himalayan communities can gain reliable access to clean water, even in extreme conditions, while preserving vital ecosystems and supporting socio-economic resilience across the region.

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2. Integrating Traditional Knowledge with Modern Technology in Water Management

(A case study of Cold Desert Region of Lahaul Valley)

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2.1 Background

Water is an essential element for life, development, and the environment, making it a valuable natural resource whose availability and management significantly impact both humans and ecosystems [7]. For millennia, communities have integrated traditional knowledge into managing water practices, constructing stepwells, harvesting monsoon rains, and glacier melts to coexist with nature's rhythms [4,5]. However, as climate change exacerbates droughts, floods, and unpredictable weather patterns [3], these age-old systems face unprecedented challenges. The Lahual and Spiti district of Himachal Pradesh, which is also considered as cold desert located at (N 32° 30' 0", E 77° 49' 59.988") has long relied on traditional water management systems to address the water shortage. For centuries, local communities have sustained themselves through time tested techniques such as *zings* (glacial water ponds), *kuhls* (an intricate network of community-built irrigation canals) traditional water use/storage methods (e.g., Nawn, or Khuds). These practices, deeply rooted in ecological knowledge and communal cooperation, have transformed scarcity into sustenance [2]. However, this cultural heritage or wisdom is facing a serious threat in the pace of climate change, resulting in glacier melt, shifting weather patterns, etc.

Water Conservation and management in Lahaul Valley: Zing, Kulhs, Snow harvesting

2.2 Challenges to traditional water management systems

Traditional water management systems experience numerous challenges due to various reasons like rapid urbanisation, technological advancements, infrastructure development, population growth, tourism activities, climate change and resource mismanagement [1]. Urbanisation replaces natural surfaces with impermeable materials, disrupting groundwater recharge and causing flooding while polluting ancient water bodies like kuhls. Technological advancements encourage dependence on modern systems such as borewells and dams, accelerating groundwater depletion while eroding indigenous knowledge. Infrastructure development fragments watersheds and destroys heritage structures, as seen with the Tehri Dam disrupting traditional guls [8]. Population growth and tourism activities further intensifies pressure on local water resources, polluting sacred sites and disrupting traditional systems like kuhls in Himachal Pradesh. Climate change exacerbates these issues by causing erratic rainfall, glacial retreat, and extreme weather, threatening time-honored water harvesting methods such as zings and ice stupas. Additionally, large-scale projects often overshadow community-led initiatives, sidelining traditional water rights and governance. The freezing cold conditions in the region during winters also adds up to the challenges. These combined pressures endanger the sustainability of traditional water management systems, underscoring the urgent need for their integration with modern technologies to ensure resilience and long-term water security [6].

2.3 Integration with Modern Technology

To address the complex challenges of water management in cold desert regions like Lahaul, the Department of Science and Technology, New Delhi, funded project titled "Water Security through Inventory and Revival of Springs using Hydro-Geological Action Research in Cold Desert Region of Himachal Pradesh" is being implemented. This initiative focuses on geo-tagging springs, monitoring water discharge, and promoting community participation to develop a comprehensive database of geo-springs. Cloud-based monitoring utilises hydro-meteorological instrumentation to collect real-time data on weather patterns, spring health, and groundwater levels, enabling informed and adaptive decision-making. Simultaneously, the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) plays a vital role in mapping springsheds and assessing artificial groundwater recharge potential. For instance, in the initial research phase in Yangrang village, Lahaul Valley, RS technology identified a critical high-altitude springshed that supports six downstream springs. Site-specific interventions, such as controlled recharge structures, were then implemented to restore water flow, demonstrating the effectiveness of targeted water management solutions. However, technology alone is not sufficient. Community management remains the cornerstone of sustainable water systems. Local villagers play a crucial role in maintaining recharge structures and monitoring springs, seamlessly blending ancestral knowledge with modern tools. This synergy not only ensures equitable water distribution but also strengthens the long-term resilience of traditional water management practices.

2.4 Recommendations

Community participation and their capacity building in the planning and implementation of water management projects, collaboration with line departments such as forest department and developing holistic approaches considering both traditional and modern knowledge are recommended for the sustainable water resource management in the Himalayan regions.

2.5 Conclusion

A sustainable solution to water scarcity in fragile ecosystems like the Lahaul Valley lies in integrating traditional water management techniques (*kuhls, Nawn,* and *Khuds*) with modern technologies such as cloud-based data, AI-driven monitoring, remote sensing, and precision irrigation systems. Transitioning from flood irrigation to efficient methods like drip and sprinkler systems minimises water waste, while community-led stewardship ensures fair distribution. Scientific tools like geo-tagging and springshed mapping further strengthen climate resilience. Scaling such hybrid models globally while blending local wisdom with technological advancements can safeguard water resources for future generations.

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3. Water Supply Dynamics and Challenges in the Himalayan States of India

(A Regional Perspective)

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3.1 Introduction

The Indian Himalayan Region (IHR) is an ecosystem that spans over 537,435 km (comprising about 16.2% of India's total geographical area) and is home to a diverse range of flora and fauna [3]. The region is characterised by high altitude, steep slopes, and extreme climatic conditions and is known for its glaciers, snow-capped mountains, and dense forests. Water resources are a vital aspect of the IHR ecosystem, which is the source of several major rivers that are crucial for agriculture and industry of the northern plains of India. The IHR also contains several wetlands, lakes, and springs that are essential for the survival of aquatic species. The ecosystem of the IHR is critical for the people of India and the region's biodiversity. Water resources, including springs, are indispensable for sustaining life in the IHR and other mountainous regions of India. However, climate change, deforestation, and unsustainable development practices are putting immense pressure on the IHR's water resources [6]. Furthermore, fulfilling the increased water demand of the floating population during the tourist season, particularly during summer, has also exacerbated the situation.

3.2 Significance of Springs

Springs are a common occurrence in the mountainous regions of India, including the IHR. Springwater sources are typically smaller in size compared to other water bodies such as rivers, lakes, and reservoirs. They are formed when water from underground aquifers flows to the surface due to geological and topographical factors. Due to their small size, springs may not seem significant, but they play a vital role in sustaining life in many regions, especially in mountainous areas where lifting water from the rivers flowing in deep gorges is economically not viable. Additionally, springs support a variety of plant and animal species that are adapted to these unique habitats. The terrace fields in the mountainous regions also depend on springs for irrigation, making them important for agriculture. Due to their unique characteristics to maintain their temperature close to the average annual temperature of the area, springs keep flowing in the high mountain area like Ladakh during the peak winter season (temperature ffi 20-30°C) when all the water bodies are frozen.

However, climate change, deforestation, and non-scientific establishment practices are putting immense pressure on these springs [7,5]. During 1961–2011, the Himalayan population grew by 250% with an annual growth rate of 3.3%, which is three times the world average growth rate [1]. This rapid growth led to accelerated urbanisation, eventually causing damage to recharge zones and degradation of the water quality of the springs [8]. Furthermore, this population surge has placed significant stress on these vital water sources. As per the NITI Aayog working group report on 'Inventory and Revival of the Springs in the Himalayas for Water Security' [4], about 50% of the Himalayan springs have either dried up or become seasonal in the last three decades.

In these circumstances, fetching water from local springs that have been flowing for centuries has become a full-time occupation for the mountain people, particularly women and children, to meet their daily needs. Reduced access to water, in turn, impacts health, hygiene, and sanitation and limits livelihood options as well. Thus, springs form the lifeline for a larger segment of the mountainous population, affecting their survival and sustenance. Despite the critical role they play, springs are in crisis.

Springs are the backbone of livelihood, agriculture, and biodiversity in the IHR; hence, United Nations Sustainable Development Goals (SDGs) such as SDG-1, i.e., No Poverty; SDG-2, i.e., Zero Hunger; SDG-5, i.e., Gender Equality; SDG-6, i.e., Clean Water and Sanitation; and SDG-15, i.e., Life on Land, can be achieved by 2030 in mountainous areas to a large extent by addressing the issues or problems related to the springs of the region. NITI Aayog has emphasised in its working group report (2018) that due to a lack of available basic databases on springs, these could not become part of the mainstream policies. Therefore, the development of a Web-GIS-based spring portal will be essential, where all state government departments, NGOs, and Research and Development (R&D) organisations can share their data collected on springs.

In view of the importance of springs in sustaining the water security in the mountainous parts of the country, Department of Water Resources, River Development and Ganga Rejuvenation (DoWR,RD & GR), Ministry of Jal Shakti (MoJS) took the decision to start the 1st spring census of the country along with the conduct of the 7th Minor Irrigation (MI) Census, 2nd Census of Water Bodies, and 1st Census of Major and Medium Irrigation (MMI) Projects under the centrally sponsored scheme 'Irrigation Census' for the reference year 2023-24 [9]. The census is being carried out by the MI (Stat.) wing of the DoWR, RD & GR, MoJS with the technical support of the National Institute of Hydrology (NIH), Roorkee, and Central Ground Water Board (CGWB). The census will be conducted entirely in digital mode, utilising a mobile app, thereby eliminating the use of paper and resulting in significant savings in resources, including time and cost. On the recommendations of NITI Aayog, rejuvenation of Springshed has been incorporated as a new activity in the Watershed Development Component of Pradhan Mantri Krishi Sinchayee Yojana (WDC-PMKSY 2.0) (project period 2021-26) [10]. Regeneration of springs is to be taken up as an activity under new-generation watershed projects to mitigate spring water depletion in the Himalayas and other 'springscapes' of India.

3.3 Recommendations

To develop the capacity among the implementing agencies working on springshed management, a resource book on "Springshed Management in Mountainous Regions of India" (MoJS, 2024) has been prepared by the experts of the field under the aegis of DoWR, RD & GR, MoJS. Various topics such as classifications of springs based on various criteria, systematic approaches for comprehensive spring mapping, instrumentation in the springshed, springshed management methodology, comprehensive guidelines for practitioners engaged in springshed management, short-term and long-term impacts of springshed management programmes, etc., have been given in detail.

Moreover, there is an urgent need to initiate a coordinated and systematic national-level programmes to revive the vulnerable springs to ensure the sustainable water supply, particularly in the mountainous states, and in the entire country in general.

3.4 Conclusion

Springs in the Indian Himalayan Region (IHR) are lifelines for millions, supporting domestic needs, agriculture, biodiversity, and livelihoods. Recognising their importance, national initiatives such as the first-ever Spring Census and inclusion of springshed rejuvenation in WDC-PMKSY 2.0 are vital steps toward restoring and conserving these resources. A coordinated, data-driven, and community-centric approach is essential to ensure the sustainability of springs and achieve key SDGs in the Himalayan region.

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4. Integrated Approach for Water Pipeline Inspection
(Water Resource Management in the Himalayan Region)

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IIT Mandi

4.1 Introduction

The Himalayan region faces unique challenges in water resource management due to its complex terrain, high altitudes, and climate variability. Water scarcity, undetected leakages, and contamination threaten sustainable water usage and infrastructure stability. To address these issues, a technology-driven approach can be used by integrating satellite data, ground sensors, drone-based monitoring, and AI analytics. In addition, a drone-based water sampling system to enhance efficiency, accuracy, and accessibility in water quality assessment can also be used.

4.2 Challenges in the Himalayan Region

4.2.1 **Difficult Terrain:** High altitudes, rugged landscapes, and frequent natural disasters such as landslides and floods make monitoring and infrastructure maintenance challenging.

4.2.2 **Remote Locations:** Many areas lack accessibility, limiting the feasibility of manual inspections and resource monitoring.

4.2.3 **Climate Variability:** Snow and glacier melt significantly impact water availability and infrastructure stability, requiring continuous monitoring and predictive management.

4.3 A Holistic Water Resource Management System

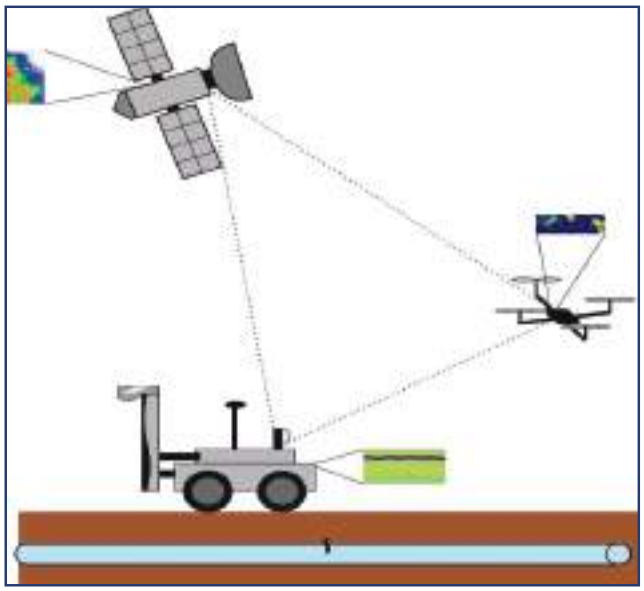

Fig.4.1. Water Resource Management System

A comprehensive framework for monitoring and managing water resources in the Himalayas, upon leverage upon three core components — ground-based sensing, aerial drone monitoring, and large-scale satellite imagery analysis, to provide real-time insights into water availability, distribution, and quality. Combining these tools can help achieve unprecedented precision and scalability in addressing challenges like water leakage detection, contamination assessment, resource monitoring, and infrastructure stability.

4.4 Ground Sensor

Automated Ground Vehicles (AGVs) with ground sensors like Ground Penetrating Radar (GPR) and thermal cameras streamline underground pipeline localisation, leak detection, and anomaly assessment. GPR maps pipelines and detects leaks, while thermal cameras spot temperature variations from leaks. Automation reduces manual inspections, enhances accuracy, and, with AI and GIS integration, optimises water distribution and predictive maintenance for sustainable water management.

Ground Sensor

4.5 Drone-based Monitoring

Drones enhance water resource and pipeline monitoring with high precision, reaching remote areas. Equipped with thermal cameras, Light Detection and Ranging (LiDAR), and optical sensors, they detect leaks, map terrain, and assess risks like erosion. Their mobility and precision complement ground sensors, bridging localised data collection with large-scale oversight.

4.6 Satellite Data Integration

Satellite data provides a regional view of water trends, complementing drones and ground sensors. Integrated with machine learning, it tracks snow cover, glacier retreat, and precipitation patterns, aiding hydrological modeling. Synthetic Aperture Radar (SAR) satellites offer all-weather monitoring, detecting terrain shifts, subsidence, and pipeline threats, while optical imagery identifies leaks via vegetation changes. Satellite data also forecasts water availability, monitors reservoirs, and highlights drought-prone areas for targeted conservation.

4.7 Smart Drone-Based Water Sampling

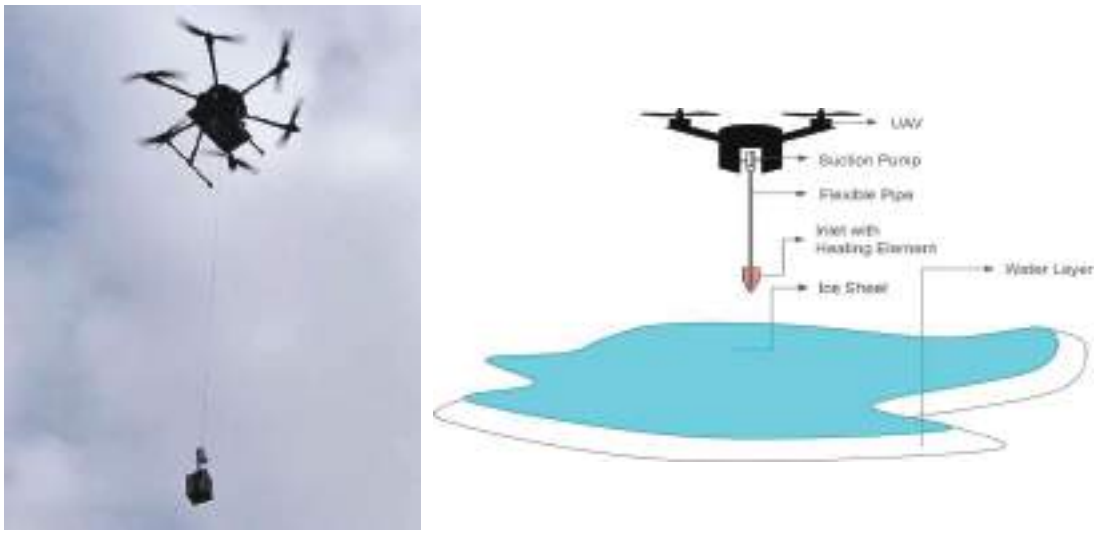

Fig.4.2. Smart Drone based Water Sampling

In the mountainous regions of Himachal Pradesh, collecting water samples is a significant challenge. Many water bodies are located in difficult-to-reach areas, surrounded by steep valleys and dangerous terrain. Currently, teams of people must trek to these locations carrying heavy equipment, which is both risky and time-consuming. During winter months or monsoon season, many sites become completely inaccessible.

Using drones for water sampling offers a practical solution to these challenges. A drone can easily fly over difficult terrain and collect samples from locations that would be dangerous or impossible for humans to reach. This approach is not only safer but also more efficient, as a drone can collect multiple samples in a single day, whereas traditional methods might take several days or even weeks to cover the same locations.

This solution involves using a specially designed heavy-lift drone equipped with a water sampling system. The drone would be a hexacopter design, capable of flying in high altitudes and carrying water samples.

4.8 Proven Success: Non-Conventional Methods (NCM) for Oil and Gas Pipeline Monitoring

A comprehensive review of robotics applications in both onshore [2] and offshore [3, 4] oil and gas industries is helpful in gaining valuable insights into this evolving field. Building on this understanding, tested autonomous unmanned aerial vehicles (UAVs) have been developed for tracking oil and gas pipelines [3], which has demonstrated the potential of aerial monitoring for managing industrial infrastructure.

Implementation of Autonomous unmanned vehicle

The NCM system, successfully commercialised in the oil and gas industry, utilises advanced sensors, drones, AGVs, and AI-driven analytics for pipeline anomaly

detection and localisation. Building on research in underground mapping of buried utilities [5], the system integrates various sensing technologies, including EM sensors, magnetic field sensing, and visual perception systems [6] to create a comprehensive monitoring solution.

This integrated approach has been effectively used to identify leaks, stress concentration zones, and structural weaknesses with high precision, reducing maintenance costs and preventing failures. By adapting NCM's capabilities to water pipeline inspection, the solution offers field-tested, reliable solution to water resource management in the Himalayan region.

4.9 Key Outcomes and Impact

4.9.1 **Automated and High-Precision Pipeline Monitoring:** Reduces human effort and improves accuracy.

4.9.2 **AI-Powered Predictive Maintenance:** Prevents failures before they happen.

4.9.3 **Real-Time Monitoring of Water Availability and Quality:** Ensures timely decision-making.

4.9.4 **Early Contamination Detection:** Prevents risks to public health.

4.9.5 **Faster and Safer Data Collection:** Drones and AGVs replace manual inspections.

4.9.6 **Early Warnings for Infrastructure Threats:** Detects land subsidence, erosion, and climate-induced risks.

4.9.7 **Sustainable Water Management:** Supports long-term conservation efforts.

4.10 Conclusion

The integration of advanced technologies offers transformative potential for water resource management. Localised pipeline and leakage detection, real-time monitoring, and automated drone-based water sampling enhance operational efficiency and responsiveness. Predictive maintenance powered by AI, along with satellite-based hydrological tracking and 3D terrain mapping, strengthens risk assessment and infrastructure planning. Furthermore, climate impact analysis provides critical insights into future water availability, enabling informed, data-driven decision-making for sustainable water governance.

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5. Application of AI, ML, and IoT in Himalayan Water Resources

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5.1 Introduction

This study explores the integration of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies to optimise the management and ensure the sustainability of water resources in the ecologically sensitive Himalayan region.

5.2 Key Concepts elaborated

Artificial Intelligence (AI) plays a crucial role in assisting stakeholders with forecasting and decision-making by utilising computational models and algorithms. This helps ensure efficient water use and management. Machine Learning (ML) develops specific tools and algorithms for various applications such as predicting water demand, maintaining water quality distribution, forecasting floods, monitoring landslides, optimising irrigation, detecting leaks, improving wastewater treatment, and modeling climate change scenarios. These advancements help in addressing numerous challenges related to water resources effectively. Furthermore, the Internet of Things (IoT) deploys calibrated sensors for online data collection, enhancing real-time monitoring and management. By providing accurate, real-time data, IoT significantly improves decision-making and management processes, contributing to a smarter and more efficient approach to managing our precious water resources.

5.3 Applications for Himalayan Water Resources

Sustainable energy-water-food nexus is a critical concept that ensures balanced resource management by integrating and optimising the use of energy, water, and food resources. This holistic approach aims to create synergies and minimise trade-offs, promoting sustainability and resilience in the face of growing global demands. Disaster mitigation and resilience are essential components of this nexus, as they enhance preparedness and response to natural disasters such as floods, droughts, and storms. By implementing advanced technologies and strategies, we can reduce the impact of these events on communities and ecosystems. Soil-water balance estimation plays a crucial role in this framework by quantifying sources and mass balancing, which helps in understanding the availability and distribution of water resources. Accurate soil-water balance estimations enable better planning and management of agricultural practices, ensuring efficient use of water and maintaining soil health. Pollution source identification is another vital aspect, as it detects and addresses pollution sources that threaten water quality and ecosystem health. By pinpointing the origins of pollutants, we can implement targeted measures to reduce contamination and protect natural resources. Lastly, numerical and analytical tools development involve building and validating models for groundwater and field scenarios. These

models provide valuable insights into complex hydrological processes, enabling more effective decision-making and resource management. Together, these elements contribute to a comprehensive and sustainable approach to managing our essential resources.

5.4 What are the challenges

The Himalayan region is particularly vulnerable to natural disasters, which occur frequently and with great severity. This area faces a range of challenges when it comes to managing and mitigating the impact of these disasters. One significant issue is data scarcity; there is a limited amount of observed data available, which makes accurate modeling and prediction difficult. Without sufficient data, it becomes challenging to develop effective strategies to protect communities and ecosystems. Additionally, the region's challenging topography complicates data collection and management. The difficult terrain not only hinders the installation and maintenance of monitoring equipment but also poses logistical challenges for researchers and emergency responders. This further exacerbates the difficulties in obtaining reliable data for accurate disaster modeling and response planning. Another critical aspect to consider is the need for sustainable development in the region. Balancing the demands of development with the imperative of environmental conservation is essential to ensure the long- term well-being of the area and its inhabitants. Sustainable development practices aim to meet the needs of the present without compromising the ability of future generations to meet their own needs. In the Himalayan region, this means implementing development projects that minimise environmental impact, protect natural resources, and enhance the resilience of communities to natural disasters. By addressing these challenges, we can work towards a more sustainable and resilient future for the Himalayan region.

5.5 Possible Solutions through AI, ML, and IoT

Data collection and preprocessing are fundamental steps in ensuring that high-quality data is available for accurate modeling. This involves gathering relevant data from various sources and transforming it into a consistent and usable format. By carefully preprocessing the data, we can remove any inconsistencies, handle missing values, and normalise the data to ensure it is ready for further analysis. Once high- quality data is obtained, model building and training can commence. This process involves developing robust models that can make accurate predictions and simulations based on the data. By training these models with a comprehensive dataset, they can learn to identify patterns and relationships within the data, enabling them to provide valuable insights and forecasts. Knowledge dissemination is a crucial aspect of this process, as it involves sharing insights and findings with stakeholders. Effective communication of these results ensures that stakeholders can make informed decisions based on the data-driven insights provided by the models. Lastly, temperature sensitivity analysis is an important study that focuses on understanding the effect of temperature variation on soil moisture readings. By analysing how changes in temperature impact soil moisture, we can better understand the dynamics of soil-water interactions and improve the accuracy of models that rely on soil moisture data. This comprehensive

approach to data collection, preprocessing, model building, knowledge dissemination, and temperature sensitivity analysis ensures that we can make well-informed decisions and develop effective strategies for various applications.

5.6 Presented Case Study

Groundwater Flow and fate of contaminant: Using a basic Average Daily Exposure (ADE) and with few assumptions, a 50-year scenario for spreading of the contaminant in subsurface was presented. This approach is just an indicator to understand the potential uses of process-based tools and generate data to train the process incorporated neural network models for improved predictions in the field of Himalayan water resources. Such a study can also be useful in understanding the brown field management and assessing associated health risks.

5.7 Conclusion

Applying AI, ML, and IoT can significantly strengthen water resource management in the Himalayas by enabling better data collection, accurate forecasting, and smarter decision-making. Despite challenges like data scarcity and tough terrain, these technologies offer practical solutions for disaster resilience, pollution control, and sustainable development, paving the way for a more secure and efficient future for the region's vital water resources.

6. Providing Safe Drinking Water at Doorstep

(Experiences of PSI in District Bageshwar, Uttarakhand)

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People's Science Institute (PSI) Dehradun

6.1 Background

Due to vulnerability to flash floods, landslides and drying springs people in remote hamlets in Himalayan villages face problem of irregular household-level water supply for drinking and domestic purposes. A drinking water and sanitation programme has been implemented in remote villages of district Bageshwar (Uttarakhand) with the active participation of local User Water and Sanitation Sub Committees (UWSSCs)[1].

6.2 Context

Pinder Valley in Kapkot block of district Bageshwar in Uttarakhand is one of the most remote valleys in the region. One of the project village Khati located at an altitude 7,350 ft. is the last village on Pindari glacier route. The area is fragile and inaccessible due to frequent landslides and road blocks during monsoon season and heavy snowfall during winter season. Natural water sources are located at a distance. Collection of water for drinking and other domestic purposes from the springs is mostly done by women and girls. Travelling up and down the hills throughout the day often makes it challenging for them. Some villages are located at a distance of about 12-13 km from nearest motorable road.

Bageshwar district, Uttarakhand

Fig.6.1. Map of Bageshwar district, Uttarakhand

The mission for providing safe drinking water (2 connections) at household level to about 1,000 households was successfully implemented in these remote areas. [3]

6.3 Approach and Methodology

Planning is done through Participatory Rural Appraisal (PRA) exercises, social and technical feasibility studies. Final plans are discussed and finalised in village level meeting. Detailed Project Report (DPR) preparation is followed by awareness programme, selection of village level facilitators and formation of institutions like User Water Sanitation Sub Committees (UWSSCs). Awareness camps are organised on water conservation, water quality testing, sanitation and health issues. Institution building done through regular monthly meetings and involvement of Self Help Groups (SHGs), and other village level institutions Instead of construction of large multi village schemes, small hamlet level decentralised schemes are prepared. Source security is part of the planning. Spring recharge plans are prepared and catchment treatment work is done wherever possible. Trenches are constructed with adequate vegetative measures through active community participation.

Pipeline fitting work

Tank color work in village Waccham and Kilapara

Increased discharge of springs is stored in storage tanks. Lift schemes (solar/ electric) installed for distribution of stored water at household level in suitable areas. Trainings are organised on water quality testing. For operation and maintenance of schemes capacity building of village level facilitators and members of UWSSC is done.

Practical exercise on water quality testing

Training and practical exercise on water quality testing

6.4 Impacts

The impacts of the project on daily water use, distance covered for collection of water, use of toilets, improved behaviour (bathing hobbit) and use of water in kitchen garden and for drinking water for livestock can be seen in Table 6.1.

Sr. No.	Changes in Water Consumption, uses	Before Project	After Project
1	Daily water use/ Person	Due to lack of water daily use was 20-30Ltr/ person (only for drinking and cooking in daily use). For washing and bathing mostly they were going to streams.	Under domestic water scheme, we **provide 70 liter / person water for daily uses** (which resulted in improved sanitation and personal hygiene)
2	Average distance of water source from Household	Before project people have to travel 300 - 400 meter (average) to take water from source	**Each household have 2 water connections** (Kitchen/ Front of House /Toilet, Washroom)
3	Toilet	Due to lack of water 40-45% people were using toilet	After Project **98-99%** people are using toilets
4	Daily Bath	10-15% people were using water for daily bath	**50-55%** people using water for daily bath
5	Kitchen Gardening	Due to lack of water only 5-6 % household were doing kitchen gardening	Due to increased availability of water **60 -70 %** household are doing kitchen gardening
6	Livestock	Water availability for livestock was less due to higher distance and labor	Water availability for livestock increased with reduced distance and labor

Table.6.1. Changes in water consumption pattern

6.5 Achievements

6.5.1 76 Decentralised hamlet level drinking water schemes constructed in 17 remote and isolated villages of Bageshwar and Kapkot blocks of district Bageshwar, Uttarakhand.

6.5.2 Water connections given to 1,215 households in the 17 villages.

6.5.3 In addition water connections were also given to 12 temples, 10 tourist huts, 10 schools, 1 inter college, 1 Auxiliary Nurse Midwife (ANM) centre. School girls and senior members from the Beneficiary households are happy with the scheme.

6.5.4 A trained cadre of 17 village level facilitators (para workers) and 150 UWSSC members was developed.

6.5.5 In seven villages of Pinder valley each household given two connections.

6.5.6 Village level facilitators and UWSSC members trained in water quality testing.

Happy Beneficiaries with household connection

6.6 Conclusion

Participatory planning and facilitation is a time-intensive but essential process, requiring strong institutional support and the active involvement of local community institutions in planning, implementation, monitoring, and evaluation [2]. Ensuring financial transparency, promoting decentralised small-scale schemes to mitigate risks from natural hazards, and focusing on source sustainability through spring recharge and village water security are critical. Equitable access, integration of wastewater and greywater management, improved drainage and sanitation, along with continuous capacity building of communities particularly in water quality testing are key components for creating resilient and sustainable water management systems.

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7. Water Security and Climate Adaption-II in Himachal Pradesh (WASCA-II)

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7.1 Intoduction

Himachal Pradesh's terrain is characterised by hills and mountains, making it crucial to manage water resources effectively. The fragile Himalayan ecosystem of the state is highly susceptible to soil erosion and land degradation. Watershed development works, such as terracing, afforestation, and water harvesting structures, have played a crucial role in conserving soil and water resources, mitigating floods and droughts, and improving agricultural productivity in the state.

7.2 Water Security and Climate Adaptation-II in Himachal Pradesh

Water Security and Climate Adaptation' in Rural India-II (WASCA-II), a bilateral project is being implemented in Himachal Pradesh from April 2022 to March 2025. Initially, the WASCA 2.0 project focused on two pilot blocks, Bangana (District Una) and Nirmand (District Kullu), for the development of a GIS-based plan for Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) in Himachal Pradesh. Additionally, the project has expanded to include five new blocks: Bhoranj and Nadaun (District Hamirpur), Chohara and Mashobra (District Shimla) and later Lambagaon block (District Kangra).

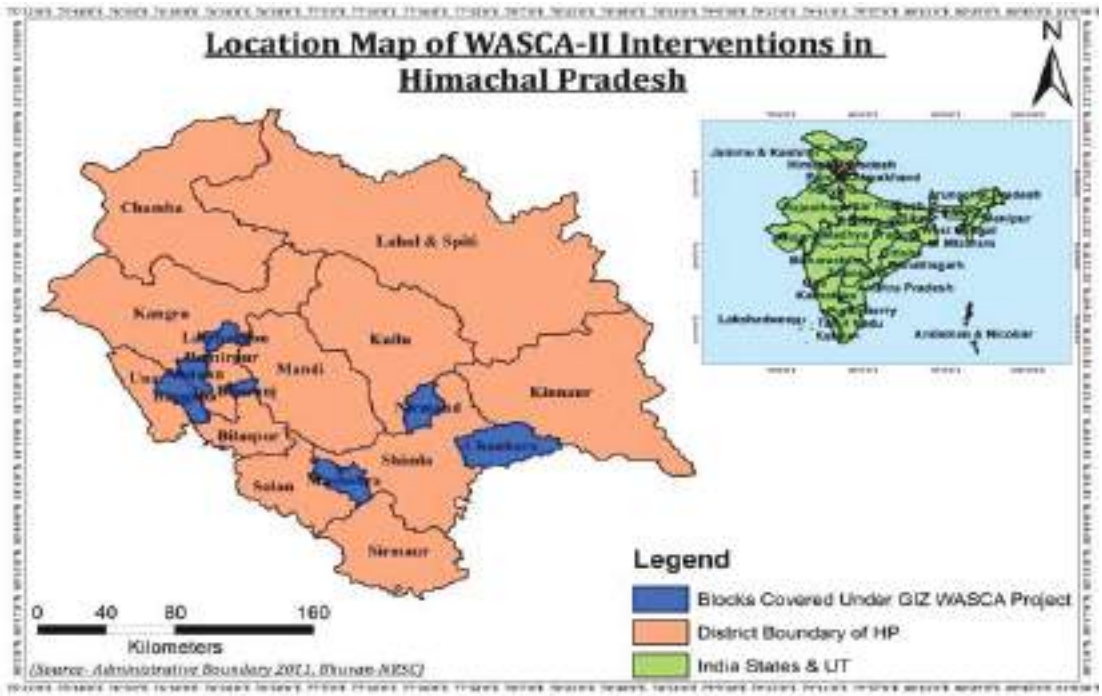

Fig.7.1. Location Map of WASCA-II in Himachal Pradesh

7.3 Object of WASCA-II

WASCA-II being implemented by GIZ with state partners is built to improve convergence with the government programmes and missions for rural development,

especially with MGNREGA, Catch the rain programmes etc., thus increasingly contributing to water security while taking climate change into account.

7.4 Training under WASCA-II

The cadre trained spans from local level (Sarpanch/ Secretary of Gram Panchayat and Gram Rozgar Sahayak) to the state level engineers and officers (Executive Engineer, Junior Engineer, Agriculture Technical Assistant, Technical Assistant, Agriculture Extension Officer). In order to enhance convergence with the agriculture department, the Director of Agriculture directs the Deputy Director of Agriculture at the district level to designate the Agriculture Extension Officer along with two to three field functionaries for the trainings. Their participation is ensured in the training sessions organised by GIZ in collaboration with Rural Development Department (RDD) for the preparation of GIS-based MGNREGA plans under the WASCA project. During the Plan Preparation Phase, participants are introduced to the functionalities of Google Earth Pro. They received a comprehensive demonstration on navigating the software and were guided on how to formulate plans specific to their respective areas.

Block- Chohara, District Shimla

Block-Bhoranj, District Hamirpur

Block-Bhoranj, District Hamirpur

Block-Nirmand, District Kullu

7.5 Promoting Composite Water Resource Management (CWRM) in Himachal Pradesh through convergence

To address climate change and water management challenges effectively, a coordinated approach is being applied in Himachal Pradesh. Overcoming silo thinking and fostering convergence and co-financing among stakeholders is essential for sustainable and resilient outcomes. The CWRM framework aims to establish district-level water plans, facilitating coordinated funding and implementation for improved water security and climate change readiness. The CWRM approach, supported by findings from the WASCA 1.0 project's pilot phase, provides valuable insights for nationwide expansion.

In Himachal Pradesh, despite numerous programmes at state and national levels contributing to CWRM, there was a need to address informational gaps and enhance convergence. There was a need to emphasise on water security and climate change adaptation through interventions like water resource assessment, supply/demand management, water quality, and cross-cutting measures.

7.5.1 **CWRM Framework:**

(i) Follows a step-by-step process for sustainable water resource management at the smallest administrative and hydrological units.

(ii) Utilises tools like remote sensing, GIS, and data on land, water, soil, and climate for effective planning.

(iii) Aims to reduce soil erosion, increase rainwater conservation, and improve land productivity.

(iv) Focuses on generating employment and uplifting local communities socially.

(v) Contributes to capacity building, stakeholder mapping, and the development of the Composite Water Resource Management Plan (CWRMP).

7.5.2 **Scaling Up and Further Capacity Building:**

(i) Expanding CWRM planning to all Gram Panchayats (GPs) in the state is crucial.

(ii) Strengthening monitoring and evaluation systems to track progress and adapt the approach.

(iii) Promoting public-private partnerships to leverage resources and expertise for water conservation.

7.5.3 **Sustainability and Long-Term Goals:**

(i) Focusing on ecosystem restoration, biodiversity enhancement, and improving soil health and water retention.

(ii) Introducing agroforestry and sustainable land management practices.

(iii) Ensuring the long-term sustainability of CWRM plans through local water user associations.

7.5.3 **Potential for Broader Impact:**

(i) Scaling the approach beyond Himachal Pradesh to other states facing similar water stress challenges.

(ii) Integrating CWRM into state policies and influencing policy decisions for long-term water security.

7.6 Way Forward

7.5.1 Enhances water conservation, management, and productivity in water-stressed regions like Himachal Pradesh.

7.5.2 Focuses on improving rural livelihoods through integrated interventions with scheme like Mahatma Gandhi NREGA.

7.5.3 Works on strengthening planning, financing, and cooperation for sustainable water management

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8. Springshed Management

(A solution for source sustainability in the Himalayan context)

Abhishek Likam

Central Himalayan Rural Action Group (CHIRAG)

8.1 Context

Himalayan springs are natural sources of freshwater originating from the Himalayas. The water from the Himalayan springs has historically been a primary source of groundwater for millions of people living in the region. Apart from providing for drinking water these springs have also been major source of base flow for rivers, supported agriculture and played a significant role in sustaining the natural ecosystem.

In recent decades, there has been increasing evidence of drying up of springs [1] or reductions in spring discharge apart from contamination of spring water. The factors causing it include climate change, rapid urbanisation, deforestation, change in precipitation, and land use change. As a result the mountain communities are facing acute water stress, affecting their lives and livelihoods and at times leading to mass outmigration.

In the Himalayas, many water distribution schemes tap water from the springs [5]. Therefore, the drying up of the Himalayan springs is a significant issue that has direct implications on the Jal Jeevan Mission and its efforts to provide safe drinking water to the rural households in Indian Himalayan Region. In such cases, most of the tap connections become less reliable, affecting the JJM's goal of providing continuous and adequate water supply.

Lack of water forces the communities, especially women and girls to compromise on a lot of aspects: their sanitation and hygiene. They are also forced to undergo physical strain in fetching water from a farther source, often leading to frequent cases of prolapsed uterus. Shortage of water further forces communities to abstain from farming, eventually augmenting concerns over food security and outmigration [6].

Therefore, Himalayan springs are crucial to ensure long-term sustainability of water supply schemes in the Himalayas. Springshed Management is an effective strategy that will ensure that the sources being tapped under the Jal Jeevan Mission maintain perennial flow of water.

8.2 Challenges and Learnings

CHIRAG's journey from pioneering the Springshed Management approach to implementing springshed management in different geographies of the country for close to two decades has been very enriching. As the initiative gains momentum across the Indian Himalayan Region, few challenges that need attention include:

8.2.1 **Lack of inventories:** A first hand enumeration of the springs and their criticality is missing. Moreover, their contribution to the larger river systems and downstream ecosystems remains eclipsed.

8.2.2 **Varying perceptions and Interpretations:** Springs vs Streams and Springshed vs Watershed is often misunderstood.

8.2.3 **Oversimplification:** Generalisation of the field investigations, poor design measures compromise the approach and pose the risks of landslides and other hazards.

8.2.4 **Poor Instrumentation:** Available data points are inadequate and unreliable. This paralyses the ability to make informed decisions based on robust scientific data.

8.2.5 **Social Inclusivity:** Communities must be involved and made integral part of the planning, management and monitoring process. Their role is crucial for perpetual management and monitoring of the sources.

8.2.6 **Narrow Vision:** The issues need a wider perspective. Water Availability-Quality-Utility are often seen in isolation.

8.2.7 **Lack of enabling policies and knowledge management:** More policy interventions for the springshed areas need to be made. For instance, many times the infrastructure development projects cut through and puncture the aquifers, access to work in the forest land/private land remains a challenge , and there are no guiding policies to check undesired actions in the catchment areas etc.

Training and Capacity Building

8.3 Way ahead

Springshed management is a promising approach to address the issue of source sustainability. However, its success demands a methodical and cautious approach. The way ahead that appears practical in the present scheme of events prioritises:

8.3.1 **Training and Capacity building:** A practical and hands-on support to the stakeholders is paramount.

8.3.2 **Cross-sectoral convergence:** This is essential for optimising the resources and bringing in synergy among the associated parties.

8.3.3 **Consortia and collaboration are way forward:** The subject of water demands collaborations and not competition. Consortia are promising way forward for achieving scales.

8.3.4 **Instrumentation and Data for informed decision making:** Building knowledge and relying on data sets will create a culture of rational decision making. The approach of springshed management needs to be seen beyond mere trenching/pits.

8.3.5 **Enabling institutional stability:** Identifying and addressing the bottlenecks at local/policy level.

8.3.6 **Need to involve and treat communities as Partners:** Building their capacities, empowering them needs to be consciously invested.

8.3.7 **Monitoring and Evaluation:** For scaling up, periodic monitoring and evaluation gives feedback for continual and timely corrections.

Monitoring and Testing of Springs

CHIRAG has always favoured collaborations. It believes that collaborations can pave way for resource optimised and innovative solutions. It expresses its interest to partner and collaborate with likeminded organisation or institution seeking to join hands and support in scaling up the approach at scale.

Monitoring Springs and Training Community

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9. Drinking Water Supply Challenges and Solutions in Lahaul Valley

(Keylong and Udaipur)

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9.1 Introduction

Lahaul Valley, nestled in the western Himalayas at an elevation of approximately 3,000 metres in Himachal Pradesh, India, is a remote, high-altitude region known for its rugged terrain and extreme climate. With harsh winters, heavy snowfall, and a short agricultural season, the valley supports a predominantly agrarian economy centred on cash crops such as peas, potatoes and cauliflower. The community has developed innovative water management practices, notably the Kuhl irrigation system, but drinking water supply faces significant challenges due to climate change, increasing tourism, and infrastructural limitations. This case study examines the water supply systems in Keylong and Udaipur, highlighting traditional practices, current challenges, and proposed solutions for sustainable water management.

9.2 Background: Lahaul Valley

Lahaul Valley's socio-economic fabric is shaped by its challenging environment. Villages are sparsely distributed, and agriculture, particularly cash cropping, is the primary livelihood. The agricultural season spans April to September, while winters (October–March) bring sub-zero temperatures and heavy snowfall, disrupting infrastructure, including water supply systems. The valley's agricultural economy, valued at approximately ₹100 crore annually, has been bolstered by the Kuhl system. Additionally, Lahaul's scenic beauty and its position on the route to Leh, Ladakh, have made it a growing tourist destination, increasing pressure on water resources.

Engagement with Community

9.3 The Kuhl System: A Model of Community Water Management

The Kuhl system, a traditional irrigation network, has been pivotal in transforming Lahaul into a commercial agricultural hub since the 1970s, when potato cultivation gained prominence.

9.3.1 **Structure and Function**: Kuhls are open canals that divert water from glacial streams to agricultural fields, ensuring efficient irrigation during the growing season.

9.3.2 **Community Governance**: Each household contributes to the maintenance and operation of the Kuhl. Before the cultivation season, communities perform rituals to pray for a prosperous harvest, reinforcing cultural ties to water resources.

9.3.3 **Economic Impact**: In 2023, the region produced over 40 metric tons of cash crops, generating ₹100 crore in revenue.

9.3.4 **Relevance to Drinking Water**: While designed for irrigation, the Kuhl system demonstrates the community's ability to manage water collectively, offering lessons for drinking water systems that coexist with government-managed infrastructure.

Cultivation of Crops through Kuhl System

9.4 Drinking Water Systems: Current State

Drinking water in Lahaul Valley is managed by government departments, supplemented by traditional community practices. However, the systems face significant challenges.

9.4.1 **Keylong Town**

(i) **Population**: Approximately 450 households, with 155 registered in the Panchayat.

(ii) **Water Supply**:

- **Summer**: Tap water from springs and streams (e.g., Beeling and Sakash Nalla) serves most households.
- **Winter**: Freezing temperatures disrupt supply systems, causing shortages.

(iii) **Infrastructure**:

- 15 standposts, each serving 15–20 households.
- 4–5 handpumps provide backup during system failures.

9.4.2 **Udaipur Town**

(i) **Population**: 237 households, with a floating population of ~1,000 during the tourism season.

(ii) **Water Supply**:

- Primarily dependent on natural springs.
- Supported by 3 handpumps and 9 borewells (5 motorised).

9.5 Emerging Challenges

The drinking water supply systems in the developing towns of Keylong and Udaipur are facing a range of interconnected challenges, driven by both environmental and socio-economic factors:

9.5.1 **Climate Change:** A noticeable decline in snowfall has significantly reduced the natural recharge of springs and streams, which serve as primary sources for both irrigation and drinking water.

9.5.2 **Rising Tourism Pressure:** Lahaul's increasing prominence as a tourist destination and its strategic location on the route to Leh have led to a sharp rise in seasonal water demand, particularly during the summer months.

9.5.3 **Water-Intensive Agricultural Practices:** The transition to cash crops, which require higher water inputs, has intensified competition for already limited water resources, placing further stress on supply systems.

9.5.4 **Winter-Induced System Disruptions:** Extended periods of sub-zero temperatures during winter months result in the freezing of pipelines and water infrastructure, causing frequent and prolonged supply interruptions.

9.6 Recommended Solutions

To address these challenges, a blend of traditional knowledge and modern technology is recommended:

9.6.1 **Community-Managed Water Systems**:

Drinking water systems modeled on the Kuhl system, empowering communities to own and maintain infrastructure, leveraging existing governance structures, should be adopted.

9.6.2 **Solar-Powered Handpumps**:

Installation of solar-powered handpumps to ensure reliable water supply during winter power outages which is suitable for remote areas with limited electricity.

9.6.3 **Integration of Traditional and Modern Technologies**:

Kuhl principles can be combined with smart irrigation systems and automated pumps to optimise water use for agriculture and domestic needs.

9.6.4 **Promotion of Water-Efficient Crops**:

Cultivation of less water-intensive crops should be encouraged to reduce pressure on water resources while sustaining the agricultural economy.

9.6.5 **Tourism Regulation:**

There is a need for implementing water conservation measures for tourism, such as mandatory water-saving practices in hotels and campsites, to manage seasonal demand.

9.6.6 **Winter-Resilient Infrastructure:**

Designing insulated or heated water supply systems to prevent freezing, can ensure year-round access.

9.7 Conclusion

The Kuhl system exemplifies the power of community-driven water management, enabling Lahaul Valley to thrive as an agricultural hub with a ₹100 crore economy. However, drinking water supply in Keylong and Udaipur faces mounting pressures from climate change, tourism, and infrastructural limitations. By building on traditional practices, integrating modern technologies, and adopting sustainable policies, Lahaul can ensure a reliable and equitable water supply for residents, farmers, and visitors. This holistic approach will preserve the valley's socio-economic vitality and cultural heritage while addressing the challenges of a changing environment.

10. Ensuring Drinking Water Supply in Hilly Terrains of Assam

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10.1 Introduction

In the hilly terrains of Assam, many habitations are home to indigenous tribal communities that rely heavily on natural sources such as springs and open wells to meet their daily drinking water and household needs. These traditional sources, often shallow and scattered across uneven landscapes, are particularly vulnerable to seasonal surface runoff and depletion. Collecting water from these sources poses significant challenges especially for women, who bear the primary responsibility for water collection. This hardship is further compounded during seasonal changes, when sources may dry up or become overexploited, forcing families to seek alternate, often more distant, water points. As a result, drinking water security in terms of availability, accessibility, and safety emerges as a critical concern in these regions, directly impacting the health and well-being of the communities.

10.2 Field Challenges existing in hilly terrains

10.2.1 **Difficult Terrain:** The rugged landscape requires residents, particularly women, to climb up and down the mountains to collect water.

10.2.2 **Source Sustainability:** No other viable source other than spring water is available. Many times, existing pond water is also used.

10.2.3 **Lack of Infrastructure:** Poor road connectivity and the absence of electricity limit access to water supply solutions.

10.2.4 **Water Quality:** The natural water sources are often contaminated, posing health risks.

10.2.5 **Excessive Demand:** Overuse of standposts leads to diminished performance, particularly in the upper reaches of the community.

10.3 Early Solutions and Challenges

Initially, the water supply scheme was conceptualised under the National Rural Drinking Water Programme (NRDWP). A gravity-based approach was adopted, with ring wells installed at the habitation level where possible. However, these efforts had several shortcomings:

10.3.1 Women continued to fetch water manually

10.3.2 Source drying up and seasonal variation of water levels

10.3.3 Excessive use of standposts reduced efficiency

10.3.4 Upper reaches experienced a limited water supply

10.3.5 Dependence on natural water flow led to unreliable service

Thaisiling Hower is a small habitation located about 60 km from Umrongso in Assam, and faces significant challenges in ensuring a reliable drinking water supply.

The habitation with 62 households and a population of 279 people of the tribal community, has the provision of primary water sources of springs and open wells. The hilly and difficult terrain, lack of electricity, and unsafe water sources pose substantial difficulties for the community.

Hence, to facilitate the community, the Thaisiling Hower piped water supply scheme (PWSS) was proposed with a provision of tapping a perennial hilly spring, from which the raw water is transported through a raw water gravity main to the treatment plant. The treated water is stored in a Clear Water Reservoir (CWR), located within the campus of the scheme. However, the Scheme was revised with the initiation of Jal Jeevan Mission (JJM), as a flagship programme to benefit the rural population.

10.4 Revised Solutions under Jal Jeevan Mission (JJM)

The basic mandate under JJM was to facilitate water supply at the doorstep of every household. However, the location of the CWR under this scheme is as such that it can facilitate water supply through a distribution network under gravity to 21 households, residing on the site of CWR. Hence, to cater to the need of balance 41 households residing in the upper reaches, another supporting CWR has been constructed in the upper level site, to facilitate water supply under gravity to these families residing in the upper reaches. So, a provision of solar energisation has been made to push the treated water from the CWR inside the scheme campus to the supporting CWR at upper level. The scheme is presently operated intermittently two times daily, to address the issues of drinking water availability, adequacy and safety.

After making the arrangements to facilitate water supply through the distribution network under gravity to all households in the habitation, efforts are initiated to provide functional household tap connection in every household, so that the troubles of water collection from roadside standposts can be avoided.

The commitment towards UN declared SDG-6.1 and the recent declaration by the Government of India about the approach named as 'Jal Jeevan Mission', has a resulted in community satisfaction from the water supply initiated through functional household tap connection from Thaisling (Hower) PWSS and this has created a record by facilitating safe drinking water to every household in the habitation through functional household tap connection.

Perhaps, this was the first PWSS in the entire India to be completed under JJM. The milestone erected by the Umrongso PHE Division (Assam) is likely to pave the way for a better future by eliminating the provisions of the roadside water stand post and thereby to benefit the community from the troublesome water collection from a distance.

Quite evidently, facilitating safe, affordable and universal easy access to water is likely to improve the quality of life in this village in a more meaningful way and even be sustained for the long. Thus, the PWSS focused on sustained water supply is likely to make our endeavour a success, to facilitate drinking water supply arrangements to benefit the inhabitants of Thaisling Hower.

10.5 Implementation Outcomes

The extensive efforts to cater to the needs in the hilly terrains of Assam, have led to following outcomes so far in the water supply sector.

10.5.1 **Operational Efficiency:**

(i) A dedicated Jal Mitra (Scheme Operator) was engaged to oversee daily operations.

(ii) Water quality testing became a regular practice.

10.5.2 **Community Involvement:**

(i) Formation of a Water Users Committee (WUC) with support from the Hill Council.

(ii) Residents committed to financial contributions for ongoing maintenance.

10.5.3 **Infrastructure Strengthening:**

(i) Focus on the distribution network improvement.

(ii) Minor repairs undertaken regularly.

10.6 Sustainability Measures

Training and Testing Water Supply Infrastructure

10.6.1 **Source Sustainability:**

(i) Collaboration with expert agencies to monitor and sustain water sources.

(ii) Spring inventory process initiated.

(iii) Thematic maps for Dima Hasao and Karbi Anglong District completed.

(iv) Use of Alternative Water Sources.

To further improve water availability, an alternative solution was introduced:

- **Pond Water Utilisation:** Treated using a horizontal roughing filter followed by rapid sand filtration, then distributed under gravity.
- **Energy Efficiency:** Solar energisation was deployed to lift and release treated water to small habitations.

10.6.2 **Disaster Response:**

(i) Preparedness for natural calamities to ensure water supply continuity.

Pond Water Utilisation and Monitoring

10.6.3 **Capacity Development:**

(i) Awareness programs, training, and orientation initiatives.

(ii) Monitoring and evaluation to bridge service delivery gaps.

Capacity Development

10.7 Current Challenges

Despite the progress made, several challenges remain:

10.6.1 Scheme Sustainability: Ensuring long-term operational efficiency and financial viability.

10.6.2 Source Exploration: Identifying and integrating new water sources with existing infrastructure.

10.6.3 Maintenance Costs: Increasing financial demands for repairs and upgradation.

10.6.4 Natural Calamities: Disruptions due to floods, landslides, and other natural disasters.

10.6.5 Sparse Population: High per capita costs due to sparsely inhabited areas.

10.8 Conclusion

The case of Thaisiling Hower showcases how strategic planning, technological interventions, and community participation can address the unique challenges of providing safe drinking water in hilly terrains. Continuous monitoring, infrastructure maintenance, and sustainable practices will be crucial for long-term success.

11. Water supply system in Ladakh

Kacho Mumtaz Ali Khan
Govt. of Union Territory of Leh Ladakh

11.1 Background

Ladakh, a region located in the northernmost part of India, faces significant challenges in providing a reliable water supply due to its extreme cold climate and rugged terrain. These challenges include:

11.2 Freezing Temperatures

11.2.1 Ladakh experiences extremely cold temperatures, particularly in winter, with average temperatures often dropping below -30°C. This can cause water sources, including rivers, streams, and pipes, to freeze, severely disrupting the water supply.

11.2.2 In areas with centralised water systems, pipes are vulnerable to freezing, rendering the water distribution network inoperable during colder months. Communities often have to rely on stored water or frozen snow and ice as alternatives.

11.3 Scarcity of Freshwater Resources

11.3.1 The region is predominantly arid, with limited rainfall and snowfall. The main source of water is the glacial meltwater, which is highly seasonal. During summer, the snow and ice melt, providing water for local communities. However, this supply dwindles as temperatures drop in winter, leaving areas with little to no fresh water for months.

11.3.2 Because of the lack of perennial freshwater bodies like lakes or large rivers, the region is heavily dependent on a few major glacial rivers and springs for water, but the supply is inconsistent and not sufficient for all needs year-round.

11.4 Limited Water Storage Infrastructure

11.4.1 The region lacks extensive water storage facilities such as large reservoirs, making it difficult to store water for dry periods. In some places, water is collected in tanks, but these storage systems are often inadequate, especially during extreme cold when water availability fluctuates.

11.4.2 The stored water may also freeze in the harsh winter, further exacerbating the supply issues.

11.5 Climate Change

11.5.1 Climate change has begun to impact the water cycle in Ladakh, with changing patterns of snowfall and glacial melt. Warmer winters may reduce snow accumulation, which in turn decreases the glacial meltwater that is crucial for water supply during warmer months.

11.4.2 In addition, erratic rainfall patterns and temperature fluctuations further complicate water management in the region.

11.6 Water Transportation and Supply Solutions

In some regions, where there is no access to reliable water infrastructure, people rely on water tankers, which are a costly and temporary solution. Transportation can be delayed due to harsh winter conditions and blockages from snow or landslides.

11.7 Lack of Proper Wastewater Treatment

In regions with a limited water supply, wastewater treatment facilities are few. This means that untreated wastewater can contaminate available water resources, which is particularly concerning given the importance of the available water sources for drinking, irrigation, and daily use.

11.8 Solutions and Innovations

Despite these challenges, several initiatives have been incorporated to mitigate the water crisis in Ladakh, especially in winter, by the PHED.

The main issue for running the water supply system in winter is freezing of pipes, delivery points and water reservoirs. To counter these challenges, many innovative methods were adopted for the successful running of the schemes. The methods adopted are as under:

11.8.1 **Protection of Source:** Due to an extreme cold climate, sometimes the sources of the schemes freeze, causing disruption of the water supply. To prevent the sources from freezing, sources like springs were covered by polycarbonate/

Polythene sheets making a green house around the source. This has helped in preventing the sources from freezing (as shown in the image below).

11.8.2 **Protection of Pipeline:** Due to extreme temperatures, usually the pipeline freezes, to prevent such things from happening, the pipes were laid 5ft below ground level (below the frost line). This method solved the pipeline freezing issues in winter (as shown in the image below).

11.8.3 **Protection of Reservoirs:** In winter, water stored in the service reservoirs faces the challenges of freezing, causing disruption of the proper supply. To address this issue, the reservoirs were provided with an earth cushion of about 1 to 1.5m thickness around the structure for insulation. This method solved the issue of water freezing in the Service reservoirs (as shown in the image below).

11.8.4 **Protection of delivery point:** One of the most vulnerable points in winter were the delivery points, which remained above ground level. As most of the houses in rural Ladakh are built in mud masonry, the inhabitants prefer keeping the delivery points outside their houses to prevent any damage. To resolve this issue, pre insulated pipes were used at the delivery points. Pre insulated pipes are specially made with 50mm think Puf foam insulation around 20mm dia High-Density Polyethylene (HDPE)/Medium-Density Polyethylene (MDPE) pipe with a casing of HDPE/Polyvinly Chloride (PVC) pipe. This method resolved the issue of freezing the delivery points (as shown in the image below).

11.8.5 **Protection of Pipes that could not be laid below the required depth due to terrain of hard rock:** In some cases, the pipelines could not be laid below the frost line due to site conditions like hard rock, marshland. In that case, pipelines are insulated using heat tape with nitrile cover, black tap, glass wool cover with chicken wire mesh and aluminium cover, to prevent the pipes from freezing (as shown in the image below).

11.8.6 **Bleeding method:** A bleeding method where the temperature is very extreme. In this case, the taps are not closed completely, instead a drop of water from the tap is allowed so that water in the pipe does not remain static, this helps in preventing the pipes from freezing (as shown in the image below).

1. **Nitrile Tube**
   - Used to prevent condensation, reduce energy and losses, prevent scratches/mechanical damage, and protect against frost on pipes.
   - Temperature range: 105 degrees Celsius to -57 degrees Celsius
2. **Taping**
   - Used to insulate and cover the gap at the joints of nitrile tubes
3. **Glass Wool**
   - Used to provide the necessary thermal insulation and packing of air.
4. **Chicken Mesh**
   - Used to bind and hold the glass wool in place.
5. **Polythene**
   - Used to protect insulation from the weather
6. **Tape**
   - Used to hold the insulation and polythene together in place
   - Aluminium cladding is used in open areas

11.9 Types of water supply schemes

12.9.1 **Gravity system:** Most of the schemes in Ladakh are gravity based schemes. Water is tapped from either streams or springs from higher reaches through pipes and delivered to the habitations.

12.9.2 **Solar-Powered Water Pumps:** These systems use solar energy to pump water from existing sources, reducing dependency on fossil fuels and making water available in remote locations.

12.9.3 **Lift schemes:** In some cases, water is lifted by using electric driven pumps into the reservoirs and distributed to the habitations.

11.10 Source augmentation and sustainability

11.10.1 **Artificial Glaciers (Ice Stupas):** These man-made ice structures help store water in the form of ice during the winter, which then melts in spring, providing water for irrigation and drinking purposes. Awareness among the people is being promoted for such methods to augment the existing water resources.

11.10.2 **Rainwater Harvesting:** Increasing awareness about capturing rainwater during the short rainy season is also being promoted, although this is still a limited solution in such an arid region.

11.10.3 **Water Conservation and Management programmes:** Education and awareness programmes on water conservation, coupled with community-based management practices, are being promoted to help local populations better manage their scarce water resources.

11.11 Conclusion

Addressing water supply challenges in Ladakh's extreme cold climate requires a combination of innovative technologies, traditional practices, and better management of natural resources, while also adapting to the changing climate patterns. The region's severe winters, limited freshwater availability, and infrastructural constraints call for more specific solutions. The proactive measures taken by the Public Health Engineering Department (PHED), such as insulating pipelines, protecting reservoirs, using solar-powered pumps, and promoting artificial glaciers, demonstrate how technological ingenuity can be effectively combined with traditional knowledge. Moreover, fostering community participation through awareness and conservation programs is essential for the long-term sustainability of water resources. Going forward, climate-adaptive planning, increased investment in decentralised infrastructure, and collaborative water governance will be key to achieving year-round, equitable water access for the people of Ladakh.

12. All weather Tap water supply in Higher reaches of Himalayas

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12.1 Introduction

Himalayan states are endowed with abundant water sources. The Himalayas are the Water Towers of Asia, as major rivers begin their journey from the glaciers in this region.

Despite having ample water sources available in the form of springs, rivulets, and open wells, the people living in these regions encounter several challenges especially during the month of winters. The Union Territory of Jammu and Kashmir, being one such Himalayan state, faces persistent difficulties in maintaining and ensuring the smooth operation of tap water supply systems. Some of the major challenges are briefly outlined below:

12.1.1 **Inaccessibility:** Most areas become inaccessible during harsh winters. Constructing permanent water supply infrastructure at higher elevations is extremely difficult. Moreover, there is a greater reliance on manual labour due to limited scope for deploying machinery. During winter, maintaining the headworks of gravity-based schemes becomes a serious challenge. These headworks are often located deep inside forests or remote locations, where mobile network connectivity is minimal or absent delaying response times to address issues in the pipeline network originating from these points. In gravity-fed systems, topography plays a dual role: while the natural slope aids in optimal pipeline design, it also leads to high costs associated with protecting the pipeline and associated structures.

12.1.2 **Terrain issues:** The region's challenging topography significantly affects the operation of water supply schemes. Slope failures during the rainy season are common, leading to temporary service disruptions. The abrupt and undulating nature of the terrain complicates pipe-laying activities, requiring additional fittings and connections. Moreover, manual trench excavation is often necessary as the rocky soil strata make excavation difficult in the absence of machinery. As discussed earlier, headworks located deep inside forests require pipes to be manually transported from storage yards, further delaying project completion.

12.1.3 **Scattered population:** The dispersed population in hilly areas poses regulatory and operational challenges for the field agencies of the Jal Shakti Department (JSD). Due to habitations being located at varying altitudes and distances from zonal storage reservoirs, pressure and discharge within the pipelines become uneven. This often leads to unauthorised interventions by locals, which disturb the system's balance. During winter, monitoring and supervision become even more difficult, hampering the consistent and reliable delivery of water.

12.1.4 **Lack of resources:** Due to the availability of work opportunities in plain and more accessible areas, water supply infrastructure projects in remote and hilly regions often face low participation from contractors. Additionally, a shortage of skilled labour further delays the achievement of completion targets for these schemes.

12.1.5 **Snowfall and freezing:** Snowfall and freezing conditions significantly limit the working season available for completing projects in hilly areas. Freezing temperatures frequently cause damage to water infrastructure, making it a routine challenge. Moreover, frequent power failures during the winter months disrupt the functioning of lift schemes and the smooth operation of Rapid Sand Filtration Plants (RSFPs). Extreme cold weather also reduces the efficiency and availability of human resources.

12.1.6 **Erratic rainfall and flash floods:** Flash floods in hilly terrain often lead to severe damage to water supply infrastructure. Pre-Settling Tanks (PSTs) and filtration plants become clogged due to high turbidity and silt-laden flows, leading to forced shutdowns. Hydrological shifts in nallahs (seasonal streams) affect water pondage levels at headworks, impacting intake. Occasional landslides in these regions further result in the breakage or blockage of pipelines.

12.2 Possible Solutions for having all weather water supply in Higher Reaches of J&K

Pipe Water Supply in J&K

12.2.1 **Inaccessibility:** Preference to simpler construction, RSFPs and Overhead Tank (OHTs) are avoided. Ground Storage Reservoir (GSRs) and Slow Sand Filtration Plants (SSFPs), which don't require high skilled labor can be instead conceived and taken up for the construction of water supply schemes in higher reaches. Single Village Schemes should be preferred over Multi Village Schemes. This shall also ease out the maintenance and repair of these schemes.

12.2.2 **Scattered population:** Separate Storages (GSRs) for each habitation be constructed separately instead of a large and bigger GSR for the whole village/ command. Further supply lines for each habitation should be designed and laid separately to cater to habitations situated at different contours. Smaller water supply schemes with sources as local springs/smaller nallas instead should be constructed in place of a multi village scheme. As the drilling machines have

limitations in terms of accessibility, it is advisable to avoid groundwater-based schemes in these terrains. Further multi stage lift schemes be avoided

12.2.3 **Lack of resources:** Component-wise tenders are being invited to encourage the participation of local contractors. Structures requiring highly skilled labor are being avoided, especially in hilly areas.

12.2.4 **Snowfall and freezing:** Due to a limited working season, priority is given to completing all maintenance-related works in snow-prone areas before the onset of winter. Pipelines must be entrenched below the freezing depth. Adequate pondage at headworks should always be maintained to prevent the freezing of intake pipes. This can be achieved by constructing temporary bunds. The construction of lift schemes should be avoided in these areas, and Operation and Maintenance (O&M) staff must be augmented during this period.

12.2.5 **Erratic rainfall and flash floods:** To prevent infrastructure damage, it is advisable to construct flexible headworks to support permanent intake structures. Additional surveillance of headworks during the winter season must be ensured. Pre-settling tanks should be constructed near headworks to remove heavy silt during flash floods. Infrastructure components should be designed to be flood-resilient, such as raised pump house floors, reinforced pipe crossings, and strong anchor blocks or support pillars.

12.2.6 **Focus on Jal Shakti Abhiyan:** Constructing rainwater harvesting and water conservation structures is a practical solution not only for groundwater recharge but also for reducing pressure on existing water supply infrastructure. Existing water bodies should be properly renovated to increase their storage capacities. As of the end of October 2024, 836 works have been completed. Greywater management must be treated as a top priority. Intensive afforestation should be carried out along sloping areas in higher altitudes. The following activities should also be taken up with urgency:

(i) Improved sanitation through SBM to prevent contamination of the water sources.
(ii) Regular water testing through laboratories and use of FTKs.
(iii) Training of women in FTK use to become water managers.
(iv) Awareness generation among the communities, especially children and women.
(v) Use of easy to maintain and easy to construct Slow sand Filtration Plants/ Filtration Galleries.
(vi) Awareness campaign through capacity building, workshops, wall writings, banners etc. across all villages especially, in hilly terrains.

12.3 Conclusion

Ensuring an all-weather tap water supply in the higher reaches of Jammu and Kashmir requires practical, context-specific solutions that address the unique challenges of inaccessibility, harsh terrain, scattered populations, limited resources, and extreme weather. By adopting simpler, locally manageable infrastructure, decentralised storage, flexible designs, and community-based conservation and awareness measures, the region can build resilient water supply systems that function year-round despite difficult conditions.

13. Watershed Development Component - Pradhan Mantri Krishi Sinchayee Yojana 2.0 (WDC-PMKSY 2.0)

Tarun Verma
Govt. of Himachal Pradesh

13.1 Introduction

The Integrated Watershed Management Programme (IWMP), launched in 2009-10 as a Centrally Sponsored Scheme (CSS), was subsequently integrated into the Watershed Development Component of the Pradhan Mantri Krishi Sinchayee Yojana (WDC-PMKSY) in 2015-16. Building on its earlier phases, the Government of India approved the continuation of the scheme as WDC-PMKSY 2.0 on 15 December 2021 for the period 2021–2026. Under this phase, a physical target of 49.50 lakh hectares has been set with an indicative Central financial outlay of ₹8,134 crore. Notably, the unit cost of project implementation has been revised upward from ₹12,000 to ₹22,000 per hectare in plain areas, and from ₹15,000 to ₹28,000 per hectare in difficult and Left-Wing Extremism (LWE)-affected regions.

States and Union Territories have been encouraged to leverage GIS and remote sensing tools for better project planning, and to promote convergence by mapping related activities from other sectors within project areas in a saturation-based approach. Acting on the recommendations of NITI Aayog, the government has also incorporated Springshed Rejuvenation as a new eligible activity under the scheme, to be implemented within the existing approved cost framework. As of now, the Department of Land Resources (DoLR) has sanctioned projects to all States and UTs to cover the entire physical target under WDC-PMKSY 2.0, and the process of releasing the Central grant is currently underway.

13.2 Objectives

13.2.1 To improve the productive potential of rainfed / degraded land through integrated watershed management;

13.2.2 To strengthen community based local institutions for the promotion of livelihoods and watershed sustainability, and

13.2.3 To improve the efficiency of watershed projects through cross learning and an incentive mechanism.

13.3 WDC-PMKSY 2.0 under Himachal Pradesh

13.3.1 A total of 26 projects were sanctioned for the state of Himachal Pradesh under Watershed Development Component of Pradhan Mantri Krishi Sinchayee Yojana (WDC-PMKSY 2.0) for the treatment of 54,000 hectares at a total cost of ₹151.20 Crores.

13.3.2 Major activities are as follows:

(i) Soil and Moisture Conservation (Contour Bunding, Gully Plugging, Drainage Line Treatment, Contour Trenching, etc.).

(ii) Construction of Water Harvesting Structures. (Farm Ponds, Check Dams, Percolation Tanks, etc.).

(iii) Water-budget based crop-planning.

(iv) Horticulture and Agriculture Development.

(v) Afforestation and Pasture Development.

(vi) Increase in Agriculture Production of the Project Area.

(vii) Generating Livelihood Activities.

(viii) Production System and Micro-Enterprises.

(ix) Training and Capacity Building of User Groups.

(x) Encouraging people's participation.

13.4 Conclusion

WDC-PMKSY 2.0 is a vital initiative for Himachal Pradesh, aiming to restore rainfed and degraded lands through integrated watershed management while strengthening community institutions and livelihoods. With targeted activities like soil conservation, water harvesting, afforestation, crop planning, and capacity building, the programme supports sustainable agriculture, boosts productivity, and promotes resilient rural communities across the state's fragile hill ecosystems.

14. Integration, Innovation, and Community Involvement

(A Way Ahead for Sustainable Water Management in Himalayan Reaches of India)

Water and Land Resources Division

NITI Aayog

14.1 Introduction

The Indian Himalayan Region (IHR) encompasses a diverse range of ecosystems and supports a significant portion of the population dependent on its water resources for agriculture, drinking, and livelihoods. This region is also referred to as the earth's third pole [4] as it has a significant contribution to global freshwater supplies with permanent glaciers. In this region, around 1.5 billion people rely on water, food, and energy sources from the Himalayas [16]. The IHR covers 10 hill states/UT: Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura, along with two partially hilly states, Assam and West Bengal. The region is home to nearly 50 million people [16]. In these regions, springs are an indispensable source of drinking water for rural households as well as sources for domestic and agricultural purposes. Springs are the visible manifestation of groundwater on the surface of the earth. For instance, a significant portion of drinking water in Uttarakhand's high-altitude region comes from springs, while in Meghalaya, all villages depend on springs for drinking water, irrigation, and livestock needs. So, springs are the lifeline for people. It is estimated that India has around five million springs, with nearly three million located in the IHR alone [16]. Springs are the primary source of water for mountain communities. So, addressing water security is a multi-dimensional approach, which involves integrating multiple stakeholders and viewpoints.

However, increasing water demand, climate-induced variability, and infrastructure gaps pose severe challenges to water security. Water scarcity is becoming a big threat to the life systems due to erratic rainfall, glacier melts, deforestation and endless anthropogenic activities. In terms of gender, women often face the burden of fetching water in the seasons of low water supply. Further, climate change and rising temperatures with fewer rainy days have accelerated the reduction in spring discharge. These menaces may deteriorate over time, with a decrease in snow cover. Therefore, a comprehensive management strategy by integrating ecology, culture and economy is the need of the hour. Initiatives such as the Jal Jeevan Mission (JJM) have made a significant impact in addressing the issue of water supply. It has helped in mapping almost 6,000 springs in the Himalayan region [12]. Yet regional-specific strategies are essential to address challenges like freezing temperatures, difficult terrain, and scattered populations.

In view of the above, an attempt is made in this paper to study the traditional and modern approaches concerning the spring water supply, which would provide a brief review of the existing systems on springs. Furthermore, there is also a requirement to explore innovative technologies for sustainable water management. This would help the policy makers are updating the use of tools for water management. The role of

communities is very essential as their involvement is crucial for waterbodies. Various case studies and practices in India may act as a change agent for these communities and also aid the policy makers.

14.2 Challenges in the Traditional and Modern approaches in household supply in Himalayan Water Management

14.2.1 **Geographical and Climatic Constraints:** The Himalayan region experiences extreme weather, from sub-zero winters to intense monsoons. Freezing temperatures result in pipeline disruptions, while landslides and cloudbursts often damage infrastructure. In addition, frequent natural calamities such as cloudbursts and landslides regularly damage infrastructure, creating persistent challenges for maintaining reliable water infrastructure for water supply.

14.2.2 **Glacial Retreat:** Being placed outside the polar zone, the Himalayan region holds the largest reserves of ice and snow, feeding ten major river systems across nine Asian countries. The region supplies water for irrigation in agricultural lands and drinking water to millions of people [18]. Studies indicate that nearly 75% of Himalayan glaciers are retreating at a concerning rate. There is a 16% decrease in snow cover from 1990 to 2001 [11]. These changes have led to negative mass balances, increasing the vulnerability of springs and underscoring the urgent need for effective spring rejuvenation efforts [17]. At higher altitudes, many springs are directly linked to glaciers, and their decline could directly impact water flow. If annual snowfall and freezing rain remain unchanged, the loss of glacial ice may not significantly alter the volume of meltwater replenishing rivers and streams each summer [15]. The melting of glaciers also helps in rejuvenating springs and recharging groundwater. Groundwater plays a crucial role in the hydrology of the Himalayan region, yet remains unpredictable. While it sustains domestic water supply and irrigation in many hill areas, excessive extraction of groundwater is resulting in depletion, causing a reduction in spring water availability across various locations [18].

14.2.3 **Depleting Natural Springs:** As per the Working Group report of NITI Aayog (2018), out of three million perennial springs, approximately 50% of springs are depleted, dried up, and have become seasonal. Around 60% of low-discharge springs that once supplied water to small settlements in the Himalayan region have shown a noticeable decline over the past few decades. In the Almora region of Uttarakhand, the report states that the number of active springs has dropped from 360 to just 60 in the last 150 years. If this happens in other regions, then this would create serious concerns. So, the depletion of natural springs may impact almost 50 million inhabitants.

14.2.4 **Infrastructure and Maintenance:** High-altitude and remote areas demand freeze-proof pipelines, insulated tanks, and robust operation and maintenance (O&M) mechanisms. The lack of skilled manpower and funding also hampers efforts. Natural disasters such as landslides, avalanches, and earthquakes frequently damage pipelines and storage tanks. Remote locations make quick repairs difficult, leading to prolonged water supply disruptions.

14.3 Innovating and Leveraging Technology for Resilience in Water Management

14.3.1 **Antifreeze Infrastructure:** Insulated Pipelines are used as one of the instruments in the Himalayan region. Modern pipeline designs consist of advanced insulation materials that help to prevent freezing and ensure uninterrupted water flow in sub-zero temperatures. Common insulation materials used are foam, fiberglass, and rubber, wherein foam and rubber are particularly effective for cold water pipelines, providing flexibility and moisture resistance [25] [1]. Fiberglass is also widely used due to its excellent thermal properties. Regions like Ladakh used to witness harsh winters, leading to the disruption of the water supply. Implementing such insulation materials in pipeline design has helped maintain continuous water flow during severe winter conditions in regions like Ladakh and the upper reaches of Himachal Pradesh [9]. Here, authorities issue advisories, emphasising the importance of insulated water pipes to prevent freezing and bursting.

14.3.2 **Heat Trace Cables:** These cables are installed alongside pipelines and use electric heating to keep water temperatures above freezing. Self-regulating heat trace cables automatically adjust their power output in response to temperature changes, providing heat where it's needed without the risk of overheating [5]. A well-designed and installed pipe freeze protection system, incorporating heat trace cables, keeps water flowing and prevents costly damage to buildings. These systems are energy-efficient and reliable, making them a cost-effective choice for maintaining water flow in sub-zero temperatures.

14.3.3 **Artificial Ice Reservoirs:** Inspired by Ladakh's ice stupas, artificial ice reservoirs are constructed to store water in the form of ice during the winter months. As temperatures rise, the ice gradually melts, releasing water for agricultural and domestic use during the dry season [2]. These reservoirs are cost-effective, sustainable, and environmentally friendly, requiring minimal resources to construct while ensuring year-round water availability. Scaling this approach across other cold regions can address seasonal water shortages and increase resilience in water-scarce communities.

14.3.4 **Digital Innovations:** Internet of Things (IoT)enabled sensors are used to track water quality, flow rates, and reservoir levels in real time, enabling prompt detection of contamination, leakage, or inefficiencies. The Ministry of Jal Shakti has integrated IoT-based sensors to monitor drinking water supply in over 600,000 villages. These sensors track flow rates, reservoir levels, and detect leakages in real-time, enhancing transparency and efficiency in rural water supply systems [10]. A study implemented an IoT-based system using microcontrollers to monitor water quality parameters of the River Pamba in real-time [2] [19]. AI-powered algorithms analyse historical data from sensors to predict potential pipeline failures, enabling proactive repairs and reducing water loss [21]. Using GIS technology, water sources such as springs are geotagged and mapped to monitor their health and recharge status. An example based on a comprehensive study in Uttarakhand to assess the status

of natural springs may be cited. Utilising remote sensing and GIS, mapping of springs was conducted across various districts and delineated springsheds [22].

This information allows policymakers to prioritise interventions in vulnerable areas. Advanced GIS tools enable detailed mapping of watersheds and underground aquifers, aiding in sustainable water extraction and recharge planning. Engaging local communities with GIS tools for participatory mapping fosters ownership and ensures that indigenous knowledge is incorporated into water management plans.

The use of GPS technology in the study of Himalayan springs has also significantly enhanced the accuracy and efficiency of data collection and analysis. By precisely mapping the location of springs, detailed spatial inventories are created, which are critical for understanding distribution patterns across varied terrains. GPS also facilitates the identification of recharge zones and catchment areas, allowing for better assessment of spring hydrology and flow dynamics. Conducting geospatial studies helps in integrating technology with assistance from local communities and expert knowledge [7].

14.3.5 **Community Involvement: Empowering Grassroots for Sustainability:** Regular Workshops and Training sessions on water conservation, spring rejuvenation efforts, rainwater harvesting, and infrastructure maintenance enhance community knowledge and self-reliance, will promote responsible water use. Encouraging more water literacy programs in schools will augment sustainability. Community engagement in integrating traditional practices and modern solutions helps in enhancing resilience and also strengthens community ownership. Empowering communities through capacity building, inclusive governance, and partnerships can transform them from passive beneficiaries to active custodians of water resources. Sustained investment in grassroots involvement ensures that water management strategies are not only sustainable but also equitable and resilient to future challenges.

14.4 Case Studies: Lessons from Exemplary Water Management Models

14.4.1 **Ladakh's Water Supply Model:** Ladakh has successfully harnessed solar energy to power water pumping and heating systems, ensuring consistent water supply even in remote areas where conventional energy sources are scarce. These systems are sustainable, cost-effective, and environmentally friendly, addressing both energy and water challenges simultaneously. Ladakh's ice stupas are a pioneering example of using artificial ice reservoirs to combat water scarcity. As mentioned in section 3.3, the model has also emphasised community ownership by training local groups to manage water infrastructure, ensuring sustainability and reducing dependency on external agencies. This participatory approach enhances efficiency and fosters responsibility. Ladakh's innovative water management efforts under the Jal Jeevan Mission (JJM) have significantly improved access to safe drinking water, particularly easing the burden on women who previously spent hours fetching water. By blending traditional knowledge with modern technology, the model has created resilient

water management systems suited for high-altitude, cold desert regions.

14.4.2 **Sikkim's Dhara Vikas programme:** The Dhara Vikas programme, initiated by the Government of Sikkim, ensures water security by disrupting the recurring cycle of water abundance and scarcity [20]. It aims to enhance the hydrological role of mountainous ecosystems as vital water sources for communities, while also contributing to disaster risk reduction by mitigating landslides and floods. The programme helps revive and rejuvenate drying springs, through an 8-step methodology [20]. These steps are: Spring Inventory and Mapping (though GPS, remote sensing, Hydrogeological Surveys, Delineation of Recharge Areas, Implementation of Recharge Structures, Afforestation and Soil Conservation, Community Mobilisation and Capacity Building, Monitoring and Impact Assessment, Policy Integration and Knowledge Sharing (through creating an environmental isotopic fingerprinting study of springs) [23].

14.4.3 **Spring Rejuvenation in Uttarakhand:** Uttarakhand has focused extensively on spring rejuvenation to address water scarcity in the Himalayan foothills. Techniques such as contour trenches, dug pits, gully plugs, and check dams have been implemented to enhance the natural recharge of springs. These efforts have resulted in improved spring discharge, ensuring a steady supply of water for drinking and agricultural purposes. This has been particularly beneficial for rainfed farming communities, reducing their vulnerability to water shortages and encouraging better irrigation practices. Civil society organisations and local communities are actively engaged in identifying critical springs and implementing recharge measures [13]. Community led efforts have been taken in the Kumaon region of Uttarakhand for ensuring spring water security [23]. These efforts involved hydrogeological mapping of springs, conflict resolution, creating Jal Samitis and monitoring springs. This led to better revival of springs despite scarce rainfall, women empowerment and overall improved water security in the region [23].

14.4.4 **Technological Pilots in Himachal Pradesh:** Initiatives are taken by IIT Mandi to introduce IoT-enabled sensors. These sensors provide real-time data on water quality, flow, and reservoir levels. These systems allow authorities and communities to respond promptly to issues such as contamination or leaks. The deployment of AI-based models to predict pipeline failures and assess water demand patterns has been acting as a game-changer for water management in Himachal Pradesh. The Government of Himachal Pradesh has also introduced innovative technologies such as snow harvesting, formation of ice-stupa, and strengthening of the source by construction of embankment, check dams etc [19].

14.4.5 **Canada's Winter Water Supply Solutions:** The various methods used in Canada are: (a) Freeze-Proof Water Systems [6] In northern Canada, heated and insulated pipelines powered by renewable energy (hydroelectric or solar) keep water from freezing during extreme winter temperatures below -40°C. (b) Seasonal Ice Roads for Infrastructure [3] Ice roads are built in winter to transport equipment and materials to remote communities, enabling water system repairs and infrastructure upgrades. (c) Integrated Tank-and-Pipeline Systems: Many communities use a mix of heated storage tanks and insulated

pipelines, with sensors to monitor water levels and prevent freezing. (d) Government Support and Policy Frameworks (CWWF programme). The Canadian government offers funding and technical support to ensure reliable water systems, with initiatives like the First Nations Water and Wastewater Action Plan for infrastructure upgrades.

14.5 Policy Recommendations

Some of the suggestions proposed are; Firstly, Establishing Nodal Agencies to streamline efforts across departments, ensuring cohesive implementation of water management strategies. These agencies can integrate both traditional wisdom and modern practices for sustainable solutions. Secondly, simplifying Forest clearances and other bureaucratic processes is critical to accelerating infrastructure development and removing bottlenecks in project implementation. Thirdly, promoting gender and social equity that helps reduce the burden on women, traditionally tasked with fetching water. Fourthly, public-private partnerships (PPPs) and community contributions should be leveraged to ensure long-term infrastructure maintenance and sustainable funding of water projects. Fifthly, bridging traditional and modern approaches: communities in the Himalayas have historically practiced effective methods such as spring shed management, snow harvesting, and "Kuhl" irrigation systems. These time-tested practices can provide valuable insights into contemporary water management. Lastly, building policy and programme synergies: initiatives like the Pradhan Mantri Krishi Sinchayee Yojana-Watershed Development Component (PMKSY-WDC) and the Jal Jeevan Mission (JJM) can offer both funding and technical support for spring rejuvenation and watershed management.

14.6 Conclusion

Sustainable water management in the Himalayan region of India demands a holistic approach that harmonises traditional knowledge, addresses existing challenges, embraces technological innovation, encourages community participation, and maintains robust governance. The unique challenges posed by the region's fragile ecosystem, unpredictable climate, and high-altitude Geography require tailored strategies that are both resilient and inclusive. By integrating these elements into water governance, India can not only address local water challenges but also contribute significantly to achieving key Sustainable Development Goals (SDGs) such as clean water and sanitation (SDG 6), climate action (SDG 13), and sustainable communities (SDG 11). Further, a combined effort from state governments, NGOs and communities is crucial for protecting springsheds. Simultaneously, there is a need for hydrological studies in identifying, protecting and augmenting groundwater recharge.

Technical efforts such as geotagging of springs, monitoring periodic discharge data during pre-monsoon, monsoon and post monsoon days, may be expedited. This also requires an investigation into hydrosocial relations with a clear understanding of the political ecologies of water. Public- private partnerships along with engagement of local communities, would be effective for large scale spring rejuvenation and sustainable spring management. So, a transdisciplinary community centric approach is proposed. Integrating scientific knowledge with traditional local wisdom, promoting stakeholder collaboration, and empowering communities can play a crucial role in

addressing water scarcity and ensuring sustainable water resource management in the Himalayan region [17].

[The views in this article are personal to the authors. It has nothing to do with the policies or programmes of the Government of India or any State Governments]

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