International Journal of Ecology and Environmental Sciences 51: 487-508, 2025
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2025.0682

Review article

Dying Traditional Water Harvesting Systems in the Indian Himalayan Region: Historical Significance, Current Challenges, and Potential Solutions

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ABSTRACT

Traditional water harvesting systems in the Indian Himalayan region have supported communities for centuries, providing an environmentally sustainable approach to managing water resources in these mountainous areas. However, these systems are increasingly at risk due to modernisation, climate change, and socio-economic transformations. This study investigates the historical importance, current challenges, and potential strategies for revitalising these essential systems. We conducted a comprehensive review of literature, government reports, and documented case studies to identify the factors contributing to the decline of traditional water harvesting practices in the Indian Himalayan region. Our analysis highlights specific case reports from various Himalayan areas, showcasing community-led restoration efforts and examining government initiatives aimed at their revival. Based on these findings, the study underscores the importance of preserving traditional knowledge and practices to ensure long-term water security and ecological stability in this fragile region.

Key words: Climate change, Socio-economic transformations, Water security, Ecological sustainability

INTRODUCTION

Humans have recognized the importance of water since their earliest existence. This is evident because all ancient civilizations documented in history and archaeology flourished along riverbanks (Sadhale and Bagh 2006). In India, major civilizations developed around deltas and along seven prominent rivers: the Ganges, Yamuna, Narmada, Cauvery, Indus, Saraswati, and Godavari. The earliest urban centres, Harappa and Mohenjo-daro, were situated along the Indus River and its tributary, the Ravi (Nair 2004). Nonetheless, numerous towns emerged even in arid and semi-arid regions with limited water availability due to climatic conditions and erratic rainfall (Tiwari and Joshi 2014). Inhabitants of these areas devised traditional water-harvesting methods that have proven effective for millennia (Mbilinyi et al. 2005). By adapting to their environment, they managed to capture rainfall from hill slopes, rooftops, and land surfaces, overcoming ecological challenges and the scarcity of permanent water sources. These systems, tailored to specific geographical contexts, resulted from centuries of experimentation and experience. Over time, these traditional water management practices evolved into cultural heritage, including recognized World Heritage Sites and older built environments that communities strive to preserve (Hein 2019). Such heritage and cultural legacies are passed down through generations when an ethnic group values and maintains the identity, traditions, and beliefs intrinsic to their place of origin (Suartika et al. 2020). Water availability is a significant barrier to agricultural growth and income (Namara et al. 2009). Water scarcity often arises from an inadequate water supply and is most severe during rapid population growth, economic expansion, and climate variability (Anonymous 2007). Many communities face varying degrees of water scarcity, even when it comes to drinking water (Negi et al. 1998). In the Indian Himalayan Region, it is estimated that the average annual flow of water is approximately 120,700 million m^3, which can generate 28,150 megawatts of energy and provides around 2,466,000 million m^3 for agricultural use. However, the potential for water use remains uncertain due to the region's complexity. Only 15% of rainwater can percolate into the ground on treeless slopes to recharge springs, while the remaining 85% runs off the surface, causing flooding (Anonymous 2015). In drought-prone areas, tanks are constructed to collect rainfall and are often used for percolation to replenish groundwater (Reddy and Behera 2009). However, when these tanks deteriorate and their catchment areas are encroached upon, the hydrological connection between surface water and groundwater systems is disrupted, leading to significant depletion of water resources (Chowdhury and Behera 2018).

Its unique geological and ecological vulnerabilities heighten the challenges of water availability in the Indian Himalayan region. Being geologically young and tectonically active, the Himalayan mountain system is highly susceptible to natural disasters, including landslides and earthquakes (Sati 2020, Pallathadka and Pallathadka 2022). The region has experienced severe flash floods, notably during the 2013 Uttarakhand disaster and the 2021 Chamoli incident, primarily triggered by glacial lake outbursts and avalanches (Yadav and Kumar 2023). The area is warming faster than the global average, leading to significant changes in precipitation patterns (Poornima et al. 2024). Vulnerability assessments indicate that over 36% of regions above 2,000 m are particularly at risk, underscoring the urgent need for targeted conservation efforts (Gupta et al. 2024). These interconnected geological and climatic issues exacerbate the already unstable water supply, emphasizing the importance of effective water resource management in maintaining ecological balance and supporting human populations. Despite these challenges, the Indian Himalayan Region (IHR) is renowned for its rich traditional knowledge of water harvesting systems (Singh et al. 2021). The Lesser Himalayas, in particular, are recognized for their innovative water conservation techniques (Sah 2023). These systems, often built collaboratively by entire communities, demonstrate remarkable engineering skills and a profound respect for water as a shared resource. Such enduring practices reflect a deep understanding of the region's unique hydrology and balanced integration with the local environment. However, the Himalayas, which have long sustained India and several densely populated Asian countries as a critical freshwater reserve (Singh et al. 2024), now face severe water scarcity issues due to over-extraction, erratic precipitation patterns, and the rapid retreat of glaciers (Tiwari and Joshi 2011, Sharma et al. 2013). Furthermore, the swift decline of traditional water systems - driven by urban expansion, colonial intrusion, modern infrastructure, and inadequate maintenance (Rawat and Sah 2009, Sharma and Ji 2024) - poses a significant threat to the livelihoods of over 75 million people who rely on these vital water sources (Sharma et al. 2024). Safeguarding Traditional Water Harvesting Systems (TWHS) while incorporating innovative solutions to address modern demands is imperative. This study aims to uncover the causes behind the decline of these age-old water harvesting practices and propose strategies to revive them, ensuring their relevance and sustainability in the fragile Indian Himalayan Region.

METHODOLOGY

The present study employs a detailed and comprehensive approach to investigate the decline of traditional water harvesting systems in the IHR. This paper includes an extensive review of existing literature, academic articles, government reports, and documented case studies. This review provides a historical, cultural, and environmental understanding of TWHS including systems like Nawn, Kuhls, Zabo, bamboo drip irrigation, and several others. The study focuses on the impacts of climate change, socio-economic transformations, and modernisation on the survival of these systems to assess their relevance in modern contexts. The study placed particular importance on identifying challenges to adapting these systems to changing climatic and demographic conditions. Comparative analyses of TWHS across various Himalayan states were undertaken to understand their ecological benefits and unique adaptations to local landscapes and climates. The study also highlighted several case studies from different Himalayan regions to offer detailed insights into community-led initiatives for reviving these systems. These case studies highlight specific factors contributing to their decline, such as urbanisation, reduced community engagement, and changing agricultural practices. In addition, the study also emphasised several government initiatives and schemes that supported the restoration of TWHS in the region. Finally, the study combines findings from literature, case studies, and policy reviews to propose practical and integrated strategies that combine modern techniques with traditional practices. This methodological framework ensures a comprehensive understanding of TWHS and its potential to enhance water security and ecological sustainability in the Indian Himalaya.

HISTORICAL AND CULTURAL SIGNIFICANCE

Human settlements grew up near water sources throughout the Stone Age. Artificial irrigation channels were constructed at the Great Bath at Mohenjo-daro (c. 2500 BC) during the Chalcolithic Period to regulate water flow (Dandawate et al. 2006). Around 5000 years ago, the Indus civilization thrived in the Indus River area with around 35,000 to 40,000 people. They improved living standards and made their neighbourhoods more resilient to natural disasters by efficiently using water for drinking, irrigating, and sanitising (Quddus 1992). India's hydrologic knowledge of water management stretches back to the Harappan Civilization and the Vedic period, with many references to water quality, water cycle, and nature-based water maintenance techniques (Singh et al. 2020). The significance of water in the Vedic people's life is emphasised in the Rigveda, one of India's earliest sacred books. It personifies water as goddess Aapodevi, who is worshipped through prayers and sacrifices, and presents it as both necessary for life and endowed with spiritual meaning (Sadhale and Bagh 2006).

The traditional knowledge, culture, and practices of water management are deeply woven into the fabric of human civilization as seen in how ancient societies flourished along rivers and other bodies of water (Sadhale and Bagh 2006, Selvaraj et al. 2022). Every tradition across the globe has a deep respect for water and has inspired communities to create and manage water bodies thoughtfully (Mishra 1993). Indigenous people and local communities deeply understand traditional water systems rooted in their lands, including methods of harvesting, storing, and distributing water. This knowledge plays a vital role in preserving ecological balance and biodiversity, safeguarding cultural and natural heritage, and enabling adaptation to changing environmental conditions (Murthy et al. 2022). Ancient societies' expertise in harnessing water's power promoted agricultural growth and, eventually, the development of urban centres. Without effective water management, neither ancient settlements nor modern societies could have fully emerged because the domestication of watermarked a pivotal shift in the world's cultural trajectory (Mithen 2010). Water use is fundamental to human life and has been essential since the dawn of civilization. The great Harappan civilization flourished on this continent from 2500 to 1500 BC, mainly due to its access to water resources. Vedic literature from 800 to 600 BC, particularly the Rigveda, is rich with hymns celebrating irrigated land, flowing rivers, ponds and wells, etc. (Agarwal and Narain 1997b).

Traditions, customs, and rituals governed a significant part of rural life, guiding communities to interact and manage water resources (Rawat and Sah 2009). Communities with deep connections to their ancestral lands, known as Indigenous Peoples, have had jurisdiction over the water and land in their territories for countless generations (Wilson et al. 2018). In Kumaon Himalaya, local communities recognised ownership over natural resources and revered water as sacred. This reverence led to the careful maintenance of water bodies and rivers or *Pani Dhara* marriages performed in these sacred spaces were fully respected by the societies (Lall 1921, Rawat and Sah 2009). In the Kumaon region, water management is viewed as a cultural duty governed by religious texts and traditional rules, where non-compliance is seen as a sin (Sah 2023). In South India, temple tanks are ancient water bodies that form essential parts of temple complexes. These tanks reflect a cultural reverence for water and are given a divine status within Hindu philosophy. Beyond their spiritual significance, these temple tanks support the environmental sustainability and economic well-being of the villages they serve. A vital yet often unnoticed function of these tanks is to serve as percolation points within town precincts. They play a crucial role in recharging groundwater and maintaining the balance of local aquifers.

However, the impact of losing this vital environmental contribution is increasingly being felt as urban tanks are drying up (Ramachandran 2006). Water sources like wells often serve as sites for cultural rituals, symbolising life and acting as community gathering spaces. Women in the mountainous regions have played a crucial role in preserving these water sources through festivals such as Nag Panchami, Sansari Puja, and Indra Puja, where the water sources are worshipped. These practices uphold the tradition of viewing water as sacred even in the historical absence of formal water protection laws (Jain et al. 2004).

OVERVIEW OF TRADITIONAL WATER HARVESTING SYSTEMS

Table 1 summarises Traditional Water Harvesting Systems in the Indian Himalayan Region, highlighting various systems across different parts of the IHR.

Ladakh (J&K)

Artificial glacier

This unique water harvesting technique has been developed to increase irrigation supplies in mountainous regions of Ladakh. These artificial glaciers are constructed close to villages at lower altitudes to ensure they begin melting in April or May earlier than natural glaciers and provide additional water precisely when crops need it most. During the winter season, channels are built to divert runoff to shaded mountain areas where water can slow down and freeze. Small' Zing' dams are constructed along slopes to slow further and freeze the water in step-like formations. As the artificial glacier melts by April, it supplies crucial water to fields just as barley crops require their first irrigation stage (locally known as Thachus) (Tundup et al. 2017, Saxena et al. 2021).

Chorus/Churres

In this system, the first step involves diverting water from the primary stream by constructing a rough dam known as the Tokpo. The primary channel, or Mayur, directs water from the Tokpo into the first pond called Zing. From there water flows through intermediate channels known as the Yura and Nangyu or Nangyura and then into smaller side channels and contour band channels called Yihu and Yang. This arrangement effectively manages water flow, ensuring distribution across various fields (Kandari et al. 2022).

Himachal Pradesh

Nawn and Baudi

Nawn is a large water-storing structure with a vast capacity. It is built using stones upon identifying the source of water. The structure has a roof and walls on three sides and a sluice at the front to block dust or unwanted debris from entering the water. A separate channel is designed for washing clothes or bathing to maintain cleanliness and ensure the primary water source remains uncontaminated. A baudi is a stone-lined pit dug in areas where water naturally percolates from the earth's surface. These circular or square structures gently slope and narrow towards a central pit. Stone steps are constructed at 20 cm intervals from top to bottom, allowing individuals to descend into the baudi to collect water when the water level drops due to seasonal changes or high usage (Sharma and Kanwar 2009, Hazarika and Hazarika 2023).

Kuhl and Ghul

These narrow surface channels utilise gravity to redirect water flow from natural streams (kuhls) and ravines (nullas) to agricultural fields. In this system, water is drawn from the high-altitude hill slopes and further extended by creating a cut in the streams with a stone embankment built primarily from piles of stones and used for irrigation. This length varies between 1-15 km, and the channel discharge is approximately 15-100 L of water per second. After reaching every field, the remaining water is drained back to the kuhls. A community kuhl serves approximately 6 to 30 farmers and covers an area of about 20 ha (Borthakur 2009, Sharma and Kanwar 2009, Bhattacharya 2015, Kumar and Katara 2020). According to the findings of Kuhl irrigation networks in Kangra Valley, it was evident that Kuhl irrigation systems were operational and supported paddy cultivation until the late 1980s. However, by the 1990s, these systems faced severe stress and became nearly defunct. The decline of these systems was due to a combination of several factors, such as reduced community participation and the surge of non-farm employment opportunities that diverted labour away from traditional irrigation practices (Sharma et al.

Table 1. Overview of traditional water harvesting systems in the Indian Himalayan Region

Sl. no.	Water Harvesting Technique	Types						State/UT	Tribe/Community	Description	Key Features	Status	Purpose			References
		SW	IC	WHP	ST	BD	CD						Do	Ir	Rs	
1	Artificial Glacier		⊕					Ladakh	Ladakh Community	Glacier melt water storing structures	Agriculture-focused	Active		⊕		Tundup et al. 2017, Saxena et al. 2021, Kandari et al. 2022
2	Bamboo Drip Irrigation					⊕		Meghalaya	Khasi and Jaintia	Bamboo pipe irrigation system	Agriculture and Domestic use	Active	⊕	⊕		Dabral 2002, Borthakur 2009, Bhattacharya 2015
3	Bogo						⊕	Arunachal Pradesh	Apatani	Community-run irrigation channels	Agriculture-focused	Declining		⊕		Dollo et al. 2009, Agarwal and Narain 1997a, Sarma and Goswami 2015
4	Cheo-Oziihi		⊕					Nagaland	Chakhesang, Angami, Zeliang, etc.	Community-run irrigation channels	Agriculture-focused	Declining		⊕		Agarwal and Narain 1997b, Sharma and Sharma 2003, Dabral 2002, Sarma and Goswami 2015
5	Chorus/Churres						⊕	Ladakh	Ladakh Comunity	Community-run irrigation channels	Agriculture-focused	Active		⊕		Kandari et al. 2022
6	Chhrudu		⊕					Himachal Pradesh	Kinnauri	Natural water sources	Ecosystem-dependent	Rare	⊕			Pophare and Balpande 2015
7	Dari	⊕						West Bengal	Santal, Gond, Kheria, etc.	Hand-dug wells	Domestic use	Declining	⊕			Kar et al. 2023, Basu et al. 2015
8	Dhan			⊕				Uttarakhand	Kumaoni	Natural ponds	Agriculture and Domestic use	Active	⊕	⊕		Rawat and Shah 2009
9	Dighi			⊕				West Bengal	Santhal, Gond, Kheria, etc.	Artificial ponds	Agriculture and Domestic use	Declining	⊕	⊕		Kar et al. 2023
10	Dong		⊕					Assam	Bodo	Community-run irrigation channels	Agriculture-focused	Declining		⊕		Sarma and Goswami 2015, Dhiman and Gupta 2011
11	Dharas			⊕				Sikkim	Lepcha and Bhutia	Integrated tanks	Domestic use	Drying	⊕			Thapa 2017
12	Duba			⊕				Tripura	Reang	Artificial and natural ponds	Agriculture-focused	Disuse	⊕	⊕		Saha and Nath 2013
13	Garh and Dara		⊕					Assam	Bodo	Irrigation channels and integrated tanks for agriculture	Agriculture-focused	Active		⊕		Bhattacharya 2015, Borthakur 2009
14	Goira and Doba			⊕				West Bengal	Santhal, Gond, Kheria, etc.	Artificial ponds	Agriculture and Domestic use	Declining	⊕	⊕		Kar et al. 2023

Sl. no.	Water Harvesting Technique	Types						State/UT	Tribe/Community	Description	Key Features	Status	Purpose			References
		SW	IC	WHP	ST	BD	CD						Do	Ir	Rs	
15	Khal			⊕				Uttarakhand	Kumaoni and Garhwali	Artificial and natural ponds	Agriculture-focused	Active	⊕	⊕		Rawat and Shah 2009
16	Khatri	⊕						Himachal Pradesh	Gaddi, Kinnauri, Lahauli, etc.	Integrated tanks for agriculture	Sustainable rainwater use	Disuse	⊕			Sharma and Kanwar 2009, Hazarika and Hazarika 2023
17	Kuhls and Ghuls		⊕					Himachal Pradesh	Gaddi, Kinnauri, Lahauli, etc.	Community-run irrigation channels	Agriculture-focused	Disuse		⊕		Kumar and Katara 2020, Bhattacharya 2015, Borthakur 2009, Sharma and Kanwar 2009
18	Mohaan or Ahal	⊕						Sikkim	Lepcha and Bhutia	Natural springs	Religious sites	Declining			⊕	Tambe et al. 2009, Thapa 2017
19	Naula				⊕			Uttarakhand	Kumaoni and Garhwali	Step wells	Religious sites and Domestic use	Drying	⊕		⊕	Sharma et al. 2023
20	Nawn and Baudi				⊕			Himachal Pradesh	Gaddi, Kinnauri, Lahauli, etc.	Step wells	Groundwater recharge	Drying	⊕			Sharma and Kanwar 2009, Hazarika and Hazarika 2023
21	Ngaralui		⊕					Manipur	Tangkhul	Community-run irrigation channels	Agriculture-focused	Disuse		⊕		Zimik and Mahapatra 2023
22	Pat Kua	⊕						West Bengal	Kurmi (Mahato)	Hand-dug wells	Domestic use	Declining	⊕			Kar et al. 2023
23	Pukur			⊕				Tripura	Reang, Bengali, Chakma, etc.	Artificial ponds	Agriculture-focused	Active	⊕	⊕		Das et al. 2015
24	Sita Kund	⊕						West Bengal	Tundra	Natural springs	Religious sites and Domestic use	Active	⊕		⊕	Kar et al. 2023
25	Tuikhur	⊕						Mizoram	Mizo	Natural springs	Ecosystem-dependent	Declining		⊕		Biswas and Azyu 2021
26	Yetbung Lingang and Linkum						⊕	Arunachal Pradesh	Adi	Community-run irrigation channels	Agriculture-focused	Active		⊕		Pattanaaik et al. 2012
27	Zabo		⊕					Nagaland	Angami, Konyak, Ao, etc.	Integrated tanks for agriculture	Agriculture and Domestic use	Active	⊕	⊕		Agarwal and Narain 1997b, Sharma and Sharma 2003, Dabral 2002, Sarma and Goswami 2015

Abrivations: **SW**-Spring Wells, **IC**-Irrigation Channels, **WHP**-Water Harvesting Pond, **ST**-Step Wells, **BD-** Bamboo Drip, **CD**-Check Dams, **Do**-Domestic, **Ir**-Irrigation, **Rs**-Religious sites

2014).

Khatri

Khatris are rectangular-shaped basins carved into the hard rocks to capture rainwater as it flows through the surrounding rocks and soil. The storage capacity of a khatri ranges from 30,000 to 50,000 L, and its construction involves excavating a horizontal tunnel of 3-4 m, which is then followed by the creation of a vertical basin. These traditional water harvesting structures are found explicitly in the Hamirpur, Kangra, and Mandi districts of Himachal Pradesh. These innovative structures play a vital role in conserving and distributing water to support individual families and the wider community (Sharma and Kanwar 2009, Hazarika and Hazarika 2023).

Chhrudu

A chhrudu is a traditional water source that channels groundwater directly through a pipe from its natural origin. In earlier times, people crafted these pipes from locally available materials, such as maggar trees or bamboo (*Bambusa arundinacea*) and the pipe was known as maggaru. Presently, maggaru pipes have largely been replaced by iron or plastic alternatives (Pophare and Balpande 2015).

Uttarakhand

Khal

These are large depressions in the mountainous region for capturing rainwater. They are typically located at the top of ridges in the saddle between two crests, where they naturally collect surface runoff. Occasionally, smaller ponds are excavated to enhance rainwater collection and ensure a reliable water supply. During the dry season, water stored in these khals becomes essential for irrigation and supports agriculture and local vegetation when other sources are scarce (Rawat and Shah 2009).

Dhan

The convergence of water from both small and large streams creates a lake-like formation. The accumulated water is used for multiple purposes, including bathing domestic animals and irrigating nearby lands. In the hilly terrains of Garhwal and Himachal Pradesh, a similar traditional water management system has long been practised, allowing communities to use these natural resources efficiently for agriculture and livestock needs (Rawat and Shah 2009).

Naula/Baoris

These are rectangular or square-shaped water harvesting structures with stairs on all four sides commonly found in Kumaon and Garhwal regions. The water comes from springs replenished as surface water seeps into the ground. Water from these sources is primarily used for drinking purposes, and to keep it hygienic, these structures are embellished with idols of deities (Sharma et al. 2023). Naulas were once a primary water source in the Kumaon region, but they are now rapidly disappearing due to neglect, pollution, and land-use changes. Over the past three decades, 3.34% of forest cover in the upper Kosi catchment has been converted to cultivated or degraded land. These shifts have diminished water resources, disrupted aquifer systems, and dried 33% of natural springs, causing water scarcity and a 25% decline in regional food production (Tiwari and Joshi 2014).

Sikkim

Mohaan/Ahal

In the mountainous regions of Sikkim, mohaan or ahal are the source of natural springs or dharas that serve as vital water sources for rural communities. Biotic interference is strictly prohibited as the indigenous communities regard these sources as sacred. Locally known as Devithans, these water sources are traditionally preserved and safeguarded from disturbances, creating a cultural foundation for spring protection (Tambe et al. 2009, Thapa 2017).

Dharas

Naturally, water drains downhill and is gathered in artificial reservoirs known as dharas. These are designed to collect water from sources such as springs, rainfall, or a combination. Villagers utilise this water for washing, irrigating kitchen and corner gardens, feeding cattle, sanitation, and other non-drinking purposes. However, the water is not considered safe for drinking due to prolonged stagnation during storage. Many residents employ various purification methods to make it suitable for consumption. Families living below the dhara source use personal plastic Polyvinyl Chloride pipes to channel water directly to their homes. However, families residing above the dhara collect the water manually. A significant portion of the region's drinking water is provided by two perennial water sources, Dumi Kua and Bar Kua, located at the mountain tops. These kuas are circular pits whose depths vary according to the underground water table (Thapa 2017).

West Bengal

Pat kua

These are semi-circular underground wells constructed mainly with bricks and cement. The depth of these wells varies depending on the underground water table. Pat kua can be owned collectively by a single household or several households. Open pat kuas often require regular maintenance and are maintained by marginalised communities. On the other hand, covered pat kuas are built to protect water from pollution and are maintained by wealthy farming communities (Kar et al. 2023).

Sita Kund

These natural water springs draw water directly from the underground water table through cracks and joints. These sources are similar to geysers and are common in plateau and mountainous regions. In the Purulia district, sita kund is considered the most ritualistic and sacred among all other water sources (Kar et al. 2023).

Dari

These are semi-circular holes constructed beside dry riverbeds to collect subsurface water during summer and are typically managed by women. While the river surface dries during summer, these structures provide access to the subsurface water flowing below and supply essential resources during the dry season (Kar et al. 2023).

Dighi

These permanent water harvesting structures are vital in sustaining ecosystem services and meeting household water demand. These water bodies are so large that they sometimes serve multiple villages. The village gram panchayat manages dighis and is not privately owned. They are permanent structures designed to collect rainwater, although the water level in dighis fluctuates between the summer and rainy seasons (Kar et al. 2023).

Goira and Doba

Goira and Doba are small water harvesting structures that are permanent or seasonal. Goiras are built near human settlements and support multiple functions, including fishing and cleaning. On the other hand, dobas are significantly smaller and are only used for animal consumption (Kar et al. 2023).

Tripura

Pukur

These are vital water-harvesting structures primarily used for irrigating fruits and vegetables around rice fields or near home yards. The pond size varies significantly in rice fields, ranging from as small as 25 m^2 to as large as 500 m^2. These structures have depths between 1.25 and 2 m with an average depth of 1.5 m. Structures like pukurs (ponds), khal (ditches), and nala (trenches) can be located in a corner or, along one side or in the middle of the rice field. These water sources are essential for life-saving irrigation during the dry season and are crucial for fish cultivation and various domestic needs (Das et al. 2015).

Duba

Duba are small ponds that are natural or man-made depressions usually used for paddy-cum-fish farming. The size of these structures usually varies between 3 to 6 m^2. The depth of the duba is typically maintained between 1 to 1.5 m, depending on the slope of the land. These structures serve multiple purposes as they provide a source of irrigation during occasional droughts. It functions as a natural fish trap that helps control weeds and loosens the soil near the roots of rice plants. Additionally, it stores uprooted paddy seedlings before transplanting them into shallow waters (Saha and Nath 2013).

Mizoram

Tuikhur

These are perennial sources of water originating from the springs and provide water for drinking, cooking, cleaning, and washing in rural areas. These waters are vital for the poorer families who rely heavily on tuikhur water to meet their daily needs. Almost every village has access to these vital water sources. However, villagers are restricted from using tuikhur water for non-essential activities like cleaning and washing during water scarcity. Recent findings have shown that Mizoram has experienced changes in precipitation, resulting in many of these water-harvesting structures drying up during the dry season.

The lack of proper spring-shed management has led many perennial springs to become seasonal, leading to water scarcity during critical periods. The existing infrastructure poses significant challenges, including those managed by the Public Health Engineering Department (PHED), which are outdated and unable to meet the growing population's needs. Also, there is a significant disparity between population growth and the available water resources. The average per capita water available is only 21 L per day, far below the required 55 L per day stipulated by the Jal Jeevan Mission guidelines. This shortfall forces villagers to rely on private operators for expensive water. Additionally, environmental issues such as soil erosion and increased runoff have negatively impacted the land's water retention capacity. This degradation further reduces the effectiveness of TWHS like tuikhurs (Biswas and Azyu 2021).

Meghalaya

Bamboo drip irrigation

This ancient technique uses bamboo pipes to transport water from hilltop springs to lower areas by harnessing the natural force of gravity. The flowing stream water is collected through bamboo pads channelled above the ground surface with support from bamboo or wooden structures. Several diversions are made depending on the agricultural requirement, and in some cases, the water is stored in a community-constructed pond for domestic and irrigation purposes. Villages like Umbir, Mawlyndep, and several others in the Rebhoi district of Meghalaya employ this traditional water harvesting technique (Dabral 2002, Borthakur 2009, Bhattacharya 2015).

Manipur

Ngaralui

It is a traditional irrigation and water-sharing system practised by the Tangkhul tribe of the Ukhrul district. A canal is constructed in this system by identifying a suitable water flow channel. This process often requires digging by hand and pilling stones. The next step is constructing a mini-dam (Ranam) to direct the water flow in the desired direction. In the final stage, the farmer conducts a water flow test and makes necessary adjustments. Once a continuous flow from the source to the field is achieved, regular water flow monitoring is carried out (Zimik and Mahapatra 2023).

Assam

Dong

The dong system, also known as Doisa, is a traditional water management practice among the Bodo people of Assam primarily to support wet rice cultivation. Dongs are water channels that direct water from perennial sources to paddy fields, ensuring a steady supply. 'Lahoni' is an instrument used to redistribute water accumulated in a small reservoir like a pond. Another structure called 'Koon', which resembles a wooden boat, is also used for harvesting water manually from the pond to the field. The main aspects of the dong system are the sustainable use of natural water resources and governance largely based on traditional community norms (Dhiman and Gupta 2011, Sarma and Goswami 2015).

Garh and Dara

Garh are large canals with big and long embankments on both sides, which are constructed to channel the river water to agricultural fields in certain parts of Assam. Dara is a small embankment created by dividing the whole paddy field into square-size plots where rainwater is stored for cultivation (Borthakur 2009, Bhattacharya 2015).

Nagaland

Zabo

Zabo (also known as the Ruza system) is an indigenous system of farming where water is harvested for irrigation, livestock, and domestic use. In this system, the forest cover at the hilltop acts as a catchment area for rainwater and is left undisturbed by the community. As rainwater flows down the slope, it moves through a series of terraces and collects in a pond-like structure in mid-slope. Below these structures are livestock such as buffalo, pigs, and cows kept in enclosures made of bamboo and wood. Water from the upper pond passes through these animal enclosures and carries rich organic nutrients to the paddy fields at the foothills, thus increasing soil fertility. This century-old farming system is still practised in Kikruma village of the Phek district of Nagaland (Agarwal and Narain 1997a, Dabral 2002, Sarma and Goswami 2015).

According to a study, the decline of the Zabo system in Nagaland is influenced by modernising forces, widespread Christian conversion, and the replacement of traditional sites for artistic development. The increasing need for income has also led many young Nagas to pursue alternative livelihoods, often in urban areas, rather than continuing with traditional farming practices. As the younger generation becomes more exposed to mass media and external cultural influences, there is a growing disconnect from traditional agricultural practices (Douglas 2017).

Cheo-oziihi

The Mezii River in Nagaland flows alongside the Angami village of Kwigema, where local villagers utilise its water to irrigate their agricultural lands. The river water is tapped at seven distinct locations across various elevations using channel diversion. The water flows down through an extended channel with numerous branches and is often directed to the terraces through bamboo pipes. One of these channels is cheo-oziihi, where "Oziihi" means water and "Cheo" refers to the individual who constructed this extensive 8 to 10 km channel with numerous branches. Each year, the local community actively maintains and clears the channels that provide irrigation to numerous terraces in Kwigema and several others in the neighbouring village (Agarwal and Narain 1997a).

Arunachal Pradesh

Bogo

Bogo is a traditional water harvesting technique practised by the Apatanis of Arunachal Pradesh using pieces of wood, bamboo, and cane, locally known as bogo (small dam) for irrigation and sometimes for agro-piscicultural activities. Each stream originating from the nearby hills is tapped and diverted through an intricate network of primary, secondary, and tertiary channels and is strategically managed to ensure equitable irrigation distribution across all fields. A regulated volume of water is diverted into feeder canals (Segang) and pipes (Huburs/Siichoo), which are then branched to feed multiple terraces. Water flow between fields is managed via a ditch (Muhgo) on the bund and two outlet pipes to maintain the desired depth. The ditch expels excess water and maintains the desired depth by putting straws/weeds at set heights. The two pipes are positioned with the upper one for overflow and the lower one for complete drainage. Water is periodically drained during agro-piscicultural activities. It is drained two to three times for weeding, which coincides with fish harvesting. In the later stages, water is completely drained from the fields to promote early ripening, increase yield, and facilitate drying during harvesting (Agarwal and Narain 1997a, Dollo et al. 2009, Sarma and Goswami 2015).

Yetbung Lingang and Linkum

The Yetbung Lingang and Linkum are traditional water conservation structures built from locally available stones, boulders, bamboo, and tokopata (*Livistona jenkinsiana* Griff) to divert the perennial stream for Panikheti and winter crop cultivation. This indigenous water management system has been widely used by the Adi tribe of Arunachal Pradesh for generations, enabling them to store water and irrigate their crops effectively (Pattanaaik et al. 2012).

CHALLENGES FOR TRADTIONAL WATER HARVESTING SYSTEMS

Modernisation and urbanisation

Figure 1 illustrates the projected water demand in India. Meanwhile, traditional water harvesting technologies are declining in modern urbanised societies due to various interconnected factors. Traditional water harvesting methods in the Himalayan region are slowly forgotten as younger generations move to urban areas for better opportunities. As towns and cities expand, traditional water sources like mountain springs, streams, and ponds are being encroached upon by new buildings, roads, and infrastructure projects. It has reduced the effectiveness of these traditional systems that have long supported the local communities (Nüsser et al. 2022). Losing these practices can lead to a disconnection between communities and their long-historical relationship with water. Also, the rise in tourism and urbanisation in the Himalayan foothills has led to increased waste generation, especially in areas like Himachal Pradesh and Uttarakhand. Additionally, the influx of people from rural areas to urban hubs like Dehradun, Shimla, and Nainital has

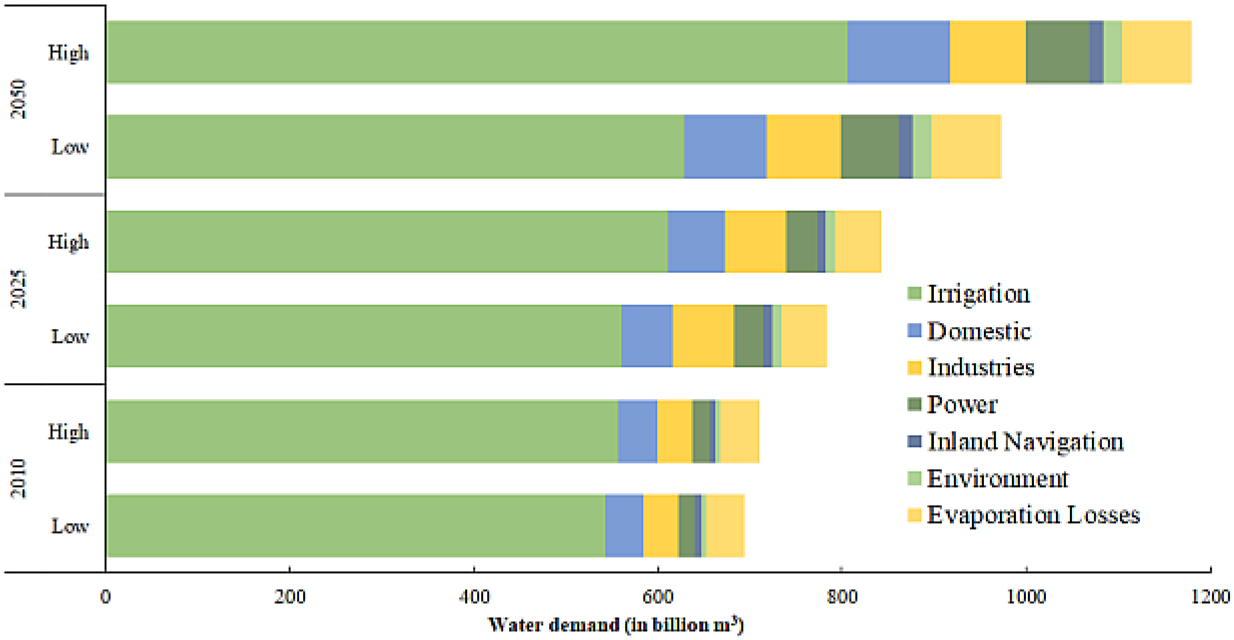

Figure 1. Projected Water Demand in India. Source: Anonymous (2013)

drastically increased the demand for water. Traditional water systems designed to serve small villages are no longer sufficient to meet the high demands of growing urban populations. This excessive groundwater extraction for agriculture and urban use in the Himalayan region is causing a significant drop in the water table. In the mid-elevation Himalayan watershed, when there are no issues with water distribution and demand for water is lower relative to its availability, users live in harmony, and there is no local or regional conflict (Babel et al. 2005). As water demand rises, disputes between users become more frequent and intense, making the pressure on water supplies more evident. Although the Himalayas have the most extensive freshwater reserves, most people who live at lower elevations experience severe water scarcity all year round. They either receive too much water during the short period of monsoon or face extreme shortages for the rest of the year (Chalise 1996). This resource scarcity seriously threatens food security, human health, and development (Pisani 1995). Usually, urban areas prioritise modern water supply systems, reducing the importance and effectiveness of traditional water harvesting practices (Tripathi et al. 2018). In the Himalayan region, government projects often prioritise large-scale irrigation projects and modern water supply networks. Traditional water harvesting systems such as rainwater harvesting and checked dams are often ignored because they are not considered technologically advanced or efficient. This increased reliance on groundwater, often promoted by government policies, has resulted in the neglect of traditional systems as communities shift to more accessible sources. Groundwater tables are eventually depleted, and water shortage problems are worsened by shifting from traditional methods to modern water management practices (Aklan et al. 2022). However, the community must balance traditional practices with modern innovations to ensure their resilience and effectiveness in the face of ongoing environmental changes.

Climate change

The centuries-old water harvesting methods used in the Himalayan region are under more and more pressure. Seasonal rainfall and glacier melt are disrupted by changing climatic patterns and are now endangering these systems (Ashraf 2013). With altered rainfall patterns, there has been an increase in flash floods, which wipe out check dams, small reservoirs, and other traditional water harvesting structures. As temperature rises, snowfall decreases, and snowmelt occurs earlier in the year than in the past. These changes not only affect the availability of water resources but also put at risk the livelihoods of communities that rely on these systems for agriculture, drinking water, and cultural practices (Singh 2016). Traditional water harvesting techniques have been greatly impacted by changes in precipitation patterns, mainly due to changes in the distribution and intensity of rainfall. Many areas now see lower yearly precipitation due to climate change, which ultimately reduces the efficiency of rainwater harvesting systems. This fluctuation affects the water supply and threatens the survival of agricultural activities that rely on these systems. This leads populations relying solely on rain-fed agriculture to experience economic difficulties and increase food insecurity (Bhattacharya 2015). As a result, people are compelled to change their farming methods or look for alternate water supplies that are not viable long-term and might worsen the state of the environment. The issue is worsened by extreme occurrences of prolonged droughts and erratic monsoons, which cause crop yields to drop and water scarcity to worsen in these sensitive areas (Isaac and Isaac 2017). Given these challenges, policymakers must implement practical measures that promote sustainable farming practices. Additionally, they must improve water management systems to help mitigate the negative impacts of climate change on vulnerable communities.

Changing socio-economic conditions

The movement of people from rural to urban regions puts tremendous pressure on the water supplies that are already available. Their migration causes them to give up their customs, which results in the loss of cultural legacy related to water management (Osti 2005, Kumar 2010). TWHS in the IHR face ignorance as modern infrastructure like bore wells and piped water systems dominate the socio-economic landscape. Increased land privatisation reduces community ownership and collective responsibility for maintaining traditional water sources. Also, financial constraints and ignorance of present-day water management techniques complicate the situation and make it more difficult for the remaining villages to adopt or revive these traditional methods. Changing weather patterns and growing water scarcity intensify these issues even further (Padigala 2016). Since modern communities are depending more and more on water-intensive crops that require more irrigation, changing dietary preferences have also led to the overexploitation of water resources (Schreier 2010). Socio-economic transformations have increased the reliance on industrial agriculture by prioritising short-term profitability over long-term sustainability. This shift has endangered the fragile ecosystems that local communities depend on for their livelihoods (Maikhuri et al. 2001). Their problems have been worsened by the decline of the traditional practices that formerly helped these communities. In a time of uncertainty, a combination of problems makes achieving food security and environmental resilience more challenging. A broad strategy that encourages the production of drought-tolerant crops is needed to tackle these interrelated issues. In addition, it should support active community participation in water management planning and sustainable farming methods (Momblanch et al. 2019). Such tactics have the potential to eventually create a more resilient agricultural system that is better equipped to manage the challenges posed by resource scarcity and growing population.

ENVIRONMENTAL AND SOCIAL IMPLICATIONS OF THE DECLINE

Decline of social cohesion

TWHS in the IHR serve not just as a response to water scarcity but are also deeply linked to the social dynamics of the community. These systems promote a participatory approach, wherein villagers were actively involved in maintenance tasks such as clearing canals, removing silt from ponds, and ensuring the effective functioning of water storage structures. Such collaborative efforts were essential for maintaining the infrastructure and nurturing a sense of shared responsibility, solidarity, and collective ownership among the community. Every individual had a role to play in the process, and thereby, the systems naturally reinforced interdependence and social cohesion. However, this collective management has been undermined with the advent of the modern harvesting system.

These systems often require technical expertise, financial investment, or specialised equipment, which only allow participation from those with the necessary skills or resources. As a result, the communal aspect of water management has been sidelined, eroding the traditional values of collective effort and shared responsibility. The lack of widespread community participation has weakened the social bonds historically nurtured through these collaborative practices. Further, the diminishing collective management has reduced social cohesion, as the shared rituals and cooperative activities that once united communities have become less common or disappeared entirely. Therefore, this decline in the traditional system comes at the cost of community solidarity.

Shifting gender roles and inequality

Declining TWHS may also have an indirect impact on women. With the increase in urban migration, the entire domestic and agricultural burden falls upon the left-behind womenfolk (Singh 2015). This may intensify their physical workload and consume significant portions of their time as they face the arduous task of gathering essential natural resources, such as fuelwood and fodder, from dwindling forests, and must also fetch water from increasingly distant sources while managing responsibilities like agriculture, livestock, childcare, and caring for elderly family members (Sharma and Banskota 2006, Agarwal 2009). According to research conducted by many professional groups, women are taken advantage of despite their dual roles, workload demands, physical fitness, nutritional state, and biological status (Borah 2015).

Moreover, the shift towards external water sources or modern infrastructure may potentially intensify gender inequalities. While men increasingly take advantage of securing employment in modern infrastructure systems, women are rarely included in these processes (Anonymous 2010). Instead, the responsibility for household water collection that typically remains with women may further entrench traditional gender roles. This unequal distribution of responsibilities potentially perpetuates disparities in power dynamics between men and women. Men benefit from improved economic prospects associated with modern infrastructure, while women's role remains tied to labour-intensive, unpaid, and undervalued tasks (Antonopoulos 2008).

Health impacts

When the environment deteriorates, women in rural areas often travel long distances to gather essential resources, negatively impacting their physical and emotional well-being. Additionally, disasters increase risk factors for violence against women and girls, such as the need to travel to isolated areas to collect water and food (Thurston et al. 2021). Their hardships become even worse because they frequently lack the time necessary to care for their children and other family members as a result of this struggle. Thus, women's health and the environment's state are intricately and directly connected, reflecting the profound impact of environmental degradation on their lives. The decline of TWHS in the IHR may have far-reaching implications for community health. The loss of these systems may force reliance on unsafe or polluted water sources, and this may elevate the risk of waterborne illnesses such as cholera, diarrhoea, and typhoid (Mogasale et al. 2018, Lin et al. 2022, Nguyen et al. 2023). The loss of these systems also reduces agricultural productivity, limiting the cultivation of staple crops like rice, maize, and wheat, leading to food insecurity and malnutrition. Fewer nutrient-rich, locally grown foods result in imbalanced diets and economic hardships for farming communities.

Furthermore, the uncertainty surrounding water availability may also cause significant mental distress, especially among those who have depended on these systems for generations. Farmers and rural populations may grapple with anxiety over diminishing water resources, making it difficult to sustain their agricultural livelihoods (Mitchell et al. 2020). Overall, the decline of these systems may disrupt water access, food security, and traditional practices, creating a cascading effect on the physical, nutritional, and mental health of Himalayan communities. Therefore, restoring traditional water systems involves more than rebuilding infrastructure; it requires revitalising the social and cultural frameworks that have supported Himalayan communities for generations.

Ecological impact

The decline of TWHS can lead to significant ecological consequences such as reduced biodiversity, soil erosion, and decreased groundwater recharge (Denison and Wotshela 2008). These changes threaten local flora and fauna and disrupt the delicate balance of ecosystems that have evolved over centuries (Ahmad et al. 1990). Such disruptions can alter water cycles and make natural habitats more vulnerable to the impacts of climate change. This reduces their resilience, ultimately affecting wildlife and human communities that depend on these ecosystems for survival (Dile et al. 2015). Changes in the local hydrology lead to more severe problems, such as water scarcity, and can intensify competition for resources and potential conflicts among communities that rely on the same resource. As a result, it becomes necessary to implement sustainable land management practices that prioritise conservation and restoration efforts to ensure the long-term health of both ecosystems and human populations (Spring et al. 2017).

Historically, TWHS, such as sand dams and rainwater catchments, have moderated runoff and increased groundwater recharge in their immediate environment. They maintain ecosystems and promote vegetation growth, supporting diverse plant and animal species (Cassin and Ochoa-Tocachi 2020). However, the absence of these systems can lead to increased drought-like conditions, particularly in semi-arid regions and limit the productivity of agricultural systems (Argaman et al. 2022, Aklan et al. 2024). Implementing these indigenous water harvesting practices has enormous benefits in the long run. However, a knowledge gap exists in combining traditional ecological wisdom with modern water management practices (Das and Mishra 2022). Because of this, the age-old knowledge and customs of the indigenous people are often ignored.

Water scarcity

During ancient India, societies faced extreme drought problems and were forced to embark on a water-stressed future. This led to the construction of various water harvesting structures that provided essential irrigation and promoted a sense of community cooperation and resource management. Before the development of modern infrastructure, these enduring structures and time-tested water management practices served as vital support systems (Selvaraj et al. 2022). However, in recent times, water scarcity has become a pressing issue in many regions, leading to increased competition for limited resources and threatening the sustainability of local communities. In the Himalayan region, TWHS like kuhls and nawn have been essential for sustaining agriculture and daily life. However, their abandonment due to modernisation and climate change now threatens both food security and community resilience. In many parts of the IHR, water scarcity makes it difficult for farmers to sustain their crops and livelihoods. This has resulted in a decline in agricultural productivity and a rise in rural poverty. As the old traditional water harvesting systems become slowly unutilised and ineffective, the communities are forced to rely on modern water infrastructure. Water scarcity due to the decline of traditional systems makes it harder for communities to share the remaining resources. This has led to growing social conflicts as different groups compete for access to water. Also, the shift to centralised water systems has made rural communities more dependent on external resources. As a result, they can no longer manage the water crisis with resilience and self-reliance.

Cultural erosion

When traditional knowledge is lost, communities may stop using long-standing methods that have successfully managed water resources. The upcoming generation may not be taught the methods and importance of these systems, which further aggravates the situation (Tiwari and Joshi 2014). Modern conveniences and technological advancements sometimes overtake sustainable methods practised for generations. This shift in belief and practices deepens the decline and distances the communities from the wisdom embedded in traditional systems. When a community loses its connection to traditional systems' spiritual and cultural importance, they may feel less motivated to care for them. This makes it harder for people to work together to protect these systems and ensure water for future generations. Education and westernisation may severely impact traditional knowledge because formal education often emphasises scientific and technological methods rather than indigenous knowledge. This creates a gap in understanding the complex interactions between regional ecosystems and traditional customs (Pelser 2001). When neglected, community ownership increases these challenges as outside parties may impose solutions that do not align with local needs or values. This approach makes it difficult for the community to manage and sustain its resources effectively. Additionally, economic pressure and changes in land use can force communities to relocate and abandon traditional practices. This loss deepens their disconnection from the land and its resources, which makes it harder to sustain their cultural heritage.

REVIVAL AND CONSERVATION STRATEGIES

Community Involvement and Empowerment

Reviving traditional water systems must involve local communities, especially older generations, who still have valuable knowledge about their construction and maintenance. Participatory approaches where the community is directly involved in restoration efforts are practical. In the Northeastern state of Mizoram, the water supply system operates through a three-tier structure involving the Public Health Engineering Department (PHED), village councils, and private households. This structure encourages local governance and community participation in managing water resources. In villages such as Suangpuilawn and Thanglailung, the village council has taken significant steps to implement large-scale rainwater harvesting. This initiative promotes self-sufficiency and empowers the community to manage their water resources effectively (Biswas and Azyu 2021). Active community participation gives different ideas and increases local commitment to these practices. Engaging local people in decision-making promotes a sense of ownership and responsibility, which is crucial for long-term water management. Those immediately affected must be willing and cooperative for conservation measures to be successful. For that purpose, it is necessary to equip the communities with the necessary skills and knowledge to manage water systems effectively. This can include practices like rainwater harvesting, watershed management, and soil conservation techniques. Involving local groups, including farmers, craftspeople, and public leaders, promotes cooperation and information sharing. These networks can help improve water systems by exchanging resources, knowledge, and assistance.

Often, women play a crucial role in preserving TWHS in the Himalayan region, where they are mostly the primary managers of these vital resources. Their responsibilities include collecting, storing, and maintaining water through systems such as springs, ponds, and tanks, which are essential for the local community's water needs. Oftentimes, when women are given roles in water management, they bring new perspectives to the table. Communities may use women's expertise to advance sustainable practices and strengthen water conservation initiatives by empowering them in water management. Women participating in community water management contribute to decision-making, resulting in more culturally appropriate conservation measures. Incorporating gender equality into water management promotes the health of the region's varied ecosystems in addition to preserving traditional practices. The Himalayan area may attain a more sustainable approach to water resource management by combining traditional knowledge, community involvement, and women's empowerment.

Government policies and support

Policy changes are urgently needed to encourage the restoration of TWHS. Government initiatives hold the potential to offer financial support, technical assistance, and education campaigns to help maintain and revive these age-old traditional practices. To find possible areas for development, the government should thoroughly document the current water harvesting systems. The government of India has established a national water policy supported by an action plan. This policy emphasises the need for a paradigm shift towards improving the performance of existing water infrastructures. In Indian states, the State Water Policy recognises water as a prime natural resource essential for survival. It stresses the importance of planning, developing, and managing water resources from a state perspective while considering local needs and conditions. The states have also initiated several measures, often with assistance from the central government, to cope with the increasing demand for fresh drinking water. One such measure is the Integrated Water Resource Management (IWRM), a significant approach, especially in response to the decline in spring water discharge. In the Indian state of Sikkim, the government has established facilities for the artificial recharge of groundwater in several districts. About 2,100 spring development, 25 cemented canals, 5,300 gabion structures, and 69,596 roof water harvesting structures were established to recharge nearly 44 million cubic meters of water (Avasthe et al. 2020). In Rural India, the Integrated Watershed Development Programme (IWDP) is a crucial stage in collecting rainfall. It enhances vegetation, soil texture and quality, prevents erosion, encourages groundwater recharge, and more. The Department of Land Resources, Ministry of Rural Development in Sikkim, initiated the IWDP in 2009-2010. Since then, the Forests, Environment & Wildlife Management Department, Government of Sikkim, has implemented 11 watershed management projects. The government should support academic and field research to understand their ecological and cultural significance. Apart from that, active participation from local communities and individuals is also crucial for repairing and maintaining these systems and keeping them running healthy. The government should provide incentive mechanisms such as rural employment programs, subsidies, and targeted financial assistance, promoting a sense of ownership and responsibility. A strong legal framework with laws and regulations must be established to ensure the long-term preservation of traditional water harvesting sites. Enforcing laws and regulations will help prevent encroachment, degradation, and over-extraction of resources.

Organising awareness campaigns at the national and regional levels can highlight the critical role of TWHS in enhancing climate resilience, mitigating floods and droughts, and conserving water resources. Community-led initiatives are important in promoting ownership and stewardship of traditional water systems. Moreover, local committees or cooperatives should be established to take responsibility for their maintenance and management, and the long-term sustainability of the systems will be achieved. Incorporating these approaches into decision-making processes enhances their effectiveness. The government can actively participate in cultural activities, celebrations, and festivals honouring long-standing water-related customs that promote cultural revival. Additionally, exchanging knowledge with other communities that have successfully maintained traditional water systems will allow communities to learn from each other and strengthen their expertise.

Integrating traditional and modern approaches

The potential for irrigation in the Indian Himalayan states (‘000 ha) is presented in Figure 2. An integrated approach that combines modern technology with traditional knowledge offers sustainable solutions without replacing or harming traditional systems.

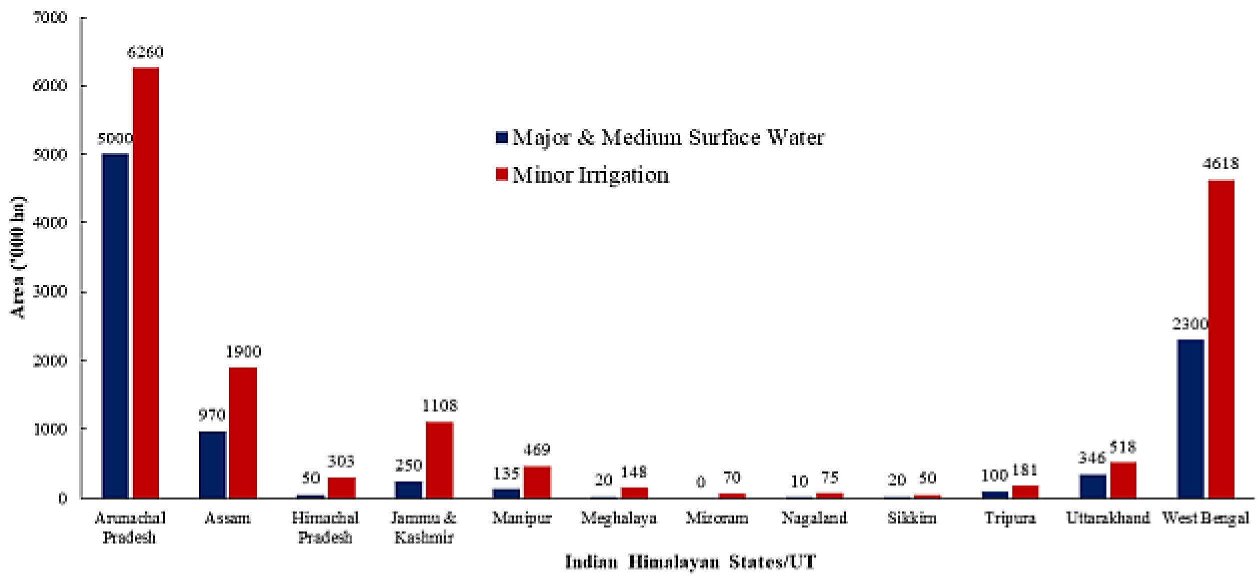

Figure 2. Irrigation Potential in Indian Himalayan States (‘000 hectares). Source: Anonymous (2013)

Combining traditional design with modern approaches will provide a bridge to long-term and efficient water management solutions. These hybrid systems not only collect and store water effectively but will also enhance the cultural and aesthetic value of the landscape. Using digital monitoring techniques such as GIS mapping, remote sensing, and information technology will allow continuous assessments of water levels, structural integrity, and environmental impacts. These technologies will provide critical data to improve system efficiency, maintain ecological balance, and adapt to future climate needs. Organisations like the People's Science Institute in Dehradun have successfully revived over 1,000 springs across ten states in the Indian Himalayan Region, supporting more than 14,000 households (Sharma et al. 2024), demonstrating the potential of combining traditional knowledge with modern science for sustainable water management.

Studying the historical and ecological aspects of traditional water systems is equally important and will help us uncover these sustainable practices that have endured over time. Moreover, insights from past usage patterns and ecological roles can guide modern strategies to ensure the practical preservation of these systems. Educational programs also play a key role in promoting respect for traditional systems and encouraging innovative ideas. Including these systems in school and college, curriculums will help inspire younger generations to adopt sustainable water management practices over time. There should be community workshops that combine traditional and modern knowledge and encourage collaboration among a diverse group of people. These efforts will deepen their understanding and empower communities to adopt these daily practices. Additionally, utilising the power of public campaigns through social media and other platforms, the importance of traditional systems in addressing water shortages and climate challenges can be highlighted to a larger audience. Thus, integrating traditional knowledge with modern innovation will lead to sustainable solutions that will honour cultural identity and uphold the values of the communities involved.

Climate adaptation

An integrated approach that combines both structural and management-based methods is needed to adapt TWHS to the challenges posed by climate change. The best example is the climate-adaptive ice stupa or artificial glacier of Ladakh. This concept is derived from earlier artificial glacier designs pioneered by engineer Chewang Norphel in the 1980s. These structures were initially developed to store glacial meltwater and have since evolved into more complex forms like the ice stupa. The ice stupa is designed to store glacial meltwater during winter months. In this method, water is diverted from streams and sprayed into the air using gravity-fed pipes, forming a pyramidal structure of ice layer by layer. This method creates a large ice mass that can be used for irrigation in the spring and summer. Unlike traditional artificial glaciers, which are flat, ice stupas have a reduced surface area exposed to wind and sun, which minimises moisture loss through sublimation. The ice stupa project addresses environmental challenges and integrates social, cultural, and economic dimensions. It gives farmers more significant control over water resources and allows them to make informed irrigation decisions. The project has been recognised as a replicable model for other communities facing similar water management issues, demonstrating the potential for climate-adaptive designs to be implemented in various contexts.

In regions where glaciers or snow are scarce, structural reinforcements are required to ensure the endurance of these systems in the face of extreme weather events. Check that dams and traditional ponds or tanks can withstand droughts and floods while functioning if they are strengthened. Furthermore, increasing the storage capacity of the present infrastructure will allow them to collect more significant amounts of water during unpredictable rainfall. This will provide a more dependable supply of water during times of scarcity. Diversifying water sources through techniques like groundwater recharge and rainfall collection reduces reliance on a single source and improves adaptation to fluctuations in local supply. Maintaining water harvesting systems also requires efficient management of catchment areas. Water quality may be maintained, water output can be increased, and sedimentation can be avoided by implementing soil conservation measures such as afforestation and erosion control within catchment areas. It is also essential to adapt traditional systems to consider changing rainfall patterns. The system will perform more efficiently if structures are designed to capture water effectively during short and intense rainfall while ensuring water can still be gathered during dry periods. Aligning these systems with climate-resilient agricultural techniques, such as planting drought-resistant crops and adopting sustainable land-use approaches will improve water management and reduce pressure on harvesting systems. This comprehensive strategy increases water availability, enhances biodiversity and soil health, and creates a more sustainable environment for future generations.

CONCLUSIONS

The Indian Himalayan Region, often called the "Water Tower of Asia," is at a critical juncture. Despite a rich history of traditional water harvesting systems, the area is now facing severe water scarcity and environmental challenges. These age-old systems, including bamboo drip irrigation, kuhls, and naulas, have historically sustained the livelihoods of millions and preserved the ecological integrity of the fragile Himalayan landscape. However, modernization, urban expansion, climate change, and declining community engagement have led to the rapid degradation and, in some cases, abandonment of these vital systems. The consequences of this decline are significant. Reduced agricultural productivity, water insecurity, and ecological imbalances threaten the livelihoods of over 75 million people who depend on local springs and streams. What were once symbols of human resilience and environmental harmony are now at risk of being forgotten. Nevertheless, there is hope in initiatives like the People's Science Institute in Dehradun, which has successfully rejuvenated over 1,000 springs. This demonstrates the potential of blending traditional knowledge with modern science. Reviving these systems is not just about managing water; it's about reclaiming a cultural heritage, empowering communities, and ensuring sustainable development in the face of climate challenges. A holistic approach is needed - one that combines policy support, community participation, and innovative solutions tailored to the unique challenges of the Indian Himalayan region. By addressing the root causes of their decline and fostering an inclusive, adaptive framework, we can help ensure that these traditional water harvesting systems continue to nourish the land and its people for generations to come.

Authors' contributions: All authors contributed equally.

Conflict of interest: Authors declare no conflict of interest.

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Received:12th January 2025
Accepted:10th May 2025