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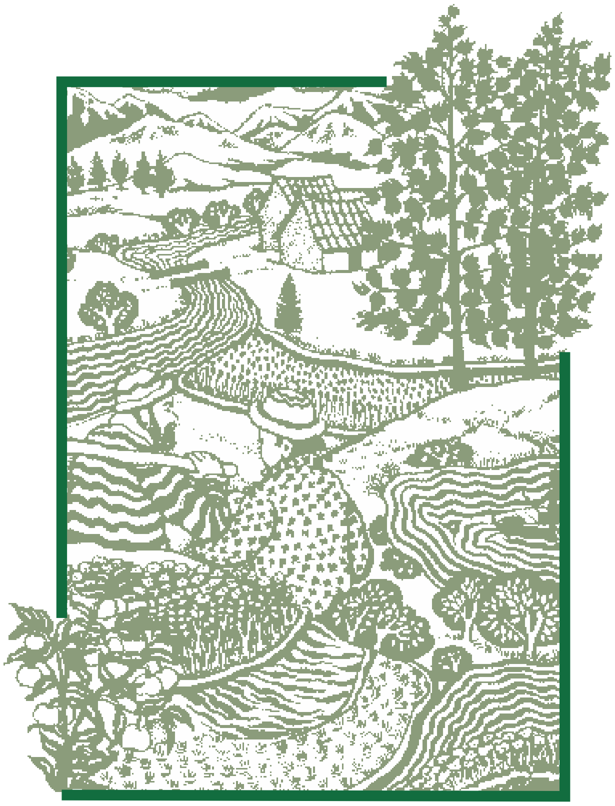

As a cold desert with extreme climate and limited precipitation, Ladakh struggles to meet its irrigation requirements. In recent years, a historical practice of grafting glaciers and a new innovative technique of building 'ice stupa' has helped communities improve irrigation access and extend the crop calendar. This Highlight looks at how combining sound science with credible local knowledge is helping people improve climate resilience.

IWMI-TATA
Water Policy Program

Water Policy Research
HIGHLIGHT

The Art of Glacier Grafting

Innovative water harvesting techniques in Ladakh

F.A. Shaheen

THE ART OF GLACIER GRAFTING
Innovative water harvesting techniques in Ladakh[*†]

Research highlight based on Shaheen (2016).

1. LADAKH: ROOFTOP OF THE WORLD

1.1 Climate and agrarian sustenance in Ladakh

Situated in the northern extremity of India, Ladakh occupies a unique niche: physiographically, climatically and culturally. (see Figure 1). The region is characterized by lofty ranges, mountain rock-walls, glaciers and snow fields interwoven with rugged mountains, covering an area of 96,701 km^2. The region is snow-clad for almost 7–8 months, the remaining being the only agriculturally productive months in the year. Lying north of the Himalayan watershed, Ladakh does not receive any summer monsoon and the annual rainfall is less than 70 mm, making it one of the world's highest cold deserts. Temperatures drop to minus 45 °C in winters and hover between 10 and 30 °C during summer. Despite hostile conditions, the region has been inhabited for centuries and its people have learnt to survive by establishing a synergistic relationship with their environment.

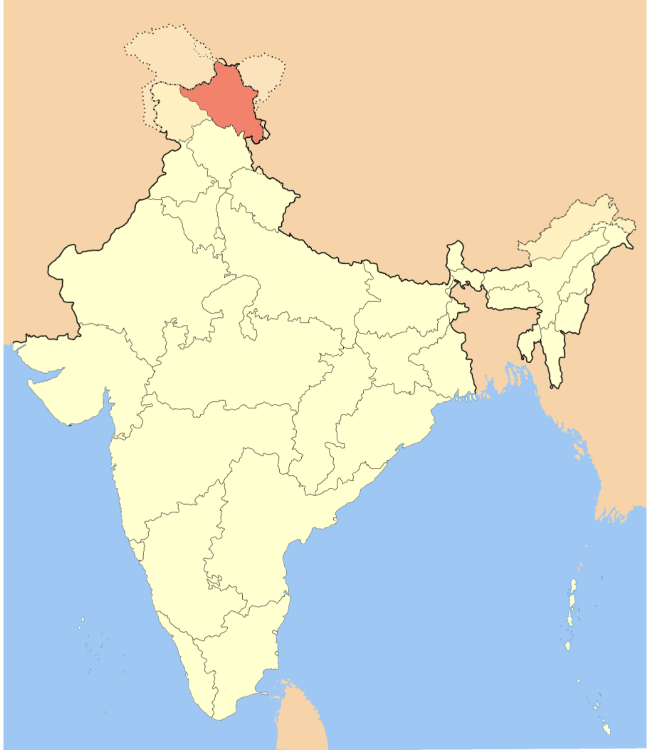

Figure 1: Location of Ladakh in India

Source: https://en.wikipedia.org/wiki/Wikipedia_talk:Notice_board_for_India-related_topics/India_maps#/media/File:India-LADAKH.svg

Glaciers and snow melt water play a very important role in the sustenance of life as they are the only source of water, be it for irrigating the fields or for any other domestic purpose. However, in the face of global warming, most Himalayan glaciers have been retreating at a rate that ranges from a few metres to several tens of metres per year (Hasnain 2002). Dry land cultivation is not possible in Ladakh. The entire 19,967 ha of cultivable land depends on irrigation from glacial melt water. There is habitation and vegetation where there is a stream. Beyond that, there is no trace of vegetation and/or habitation for miles, only long unending stretches of desert plains until another patch of greenery and human dwelling surrounding the streak of a small stream. The agriculture season in Ladakh begins in April with the melting of snow in fields. The melting is often late, delaying the availability of water for irrigation and the sowing of crops, thereby, adversely affecting crop production. The summer season in the region is of short span and mono-cultured. So, spring is the most crucial season for farmers to begin the sowing process. Very little water comes down through streams during the spring as the temperature at the high mountain peaks, where snow/natural glaciers are inhabited, is too low for the snow/glacier to start melting.

1.2 Traditional water harvesting systems

Ladakh's traditional farming system has been included in the FAO list of "Globally Important Agriculture Heritage Systems (GIAHS)", worthy of being preserved and conserved. In order to adapt and mitigate the impacts of global and climatic changes, the region is experimenting with new techniques based on traditional knowledge blended with modern science centring around water management to sustain the livelihoods in harsh environs. Be it the creation of artificial glaciers to augment the first irrigation in April-May when seeds are sown or the newly innovated technique of forming *ice stupas* to make barren lands green as well or formation of *Zhongs* for water conservation.

*This Highlight is based on research carried out under the IWMI-Tata Program (ITP) with additional support from the CGIAR Research Program on Water, Land and Ecosystems (WLE). It is not externally peer-reviewed and the views expressed are of the author/s alone and not of ITP or its funding partners.
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In order to overcome water scarcity during the sowing season, need was felt to develop a technique that would ensure water availability to farmers during critical sowing period (April–May). Chewang Norphel, a retired local civil engineer of Leh and National Prize Award winner, known to his men as the 'ice man', came with a solution of creating artificial glaciers. Norphel's big idea came from a small observation of water rushing out of pipe in the lane near his house. At the centre of the torrent, water rushed out and flowed on while at its sides, it slowed down and froze. The water was freezing in stages as it lost momentum. This inspired Norphel to make artificial glaciers. The first artificial glacier experiment was undertaken in 1987 at Phuktse Pho village in Leh district and spread to other villages after establishing successful performance. To date, ten artificial glaciers have been created with a community based approach, keeping in view the farmers' demand.

2. Artificial Glaciers

2.1 Design, structure and icing

Artificial glacier is an intricate network of water channels and check dams along the upper slopes of the village valley. The technology for creating artificial glaciers consists of three main components: head-works or diversion channels; main artificial glacier structure; and distribution network. Water from the main stream is diverted by constructing a long channel created with the help of dry stonewall across the hill slope. The length, breadth and depth of the channel vary with the slope of the hill and the estimated discharge of the stream. The stone wall is erected with the help of locally available material and chassed with organic manure mixed with soft soil. The manure and soil mixed with shrubs and plant material strengthen the wall. No other concreting or cementing material is used; thus, minimizing the cost.

The process of artificial glacier formation and site selection has some basic pre-requisites. Discharge data from the main stream is used to ascertain whether water remains available throughout the winter. The site for the glacier should be shaded to prevent/minimize the effect of direct exposure to sun shine. Ideally, the site should be in plain area with 20-30° gradient for the water to freeze into ice sheets. Further, the site should be at a lower altitude to facilitate early melting, preferably between 3,350 and 4,267 m. Finally, the site should be near a village so that water is available near the cultivated fields.

The diversion channel is constructed across the hill slopes to the site of artificial glacier formation. Construction of snow barrier bund/ice retaining bund is done with dry stone masonry in crate wire on the lower side of diversion channel. The length of the glacier and the number of barrier bunds depend on the slope at the glacier site. Lower the slope, more will be the length and fewer will be the bunds and vice versa. If the stream is very wide and has a mild slope, the bunds are constructed in a series, parallel to each other. The number and dimensions of the bunds depend on the discharge available in the stream during peak winter. In November, when winter starts, some locally available wild grasses are put on the base of the dry bund to plug the void and help instant freezing. If the stream is narrow with a steep gradient, it is diverted by constructing a gravitational channel so that water can flow through various small outlets. The process of ice formation continues for 3–4 months and a huge reserve of ice accumulates on the mountain slope, aptly termed '*artificial glacier*' (see Figure 2).

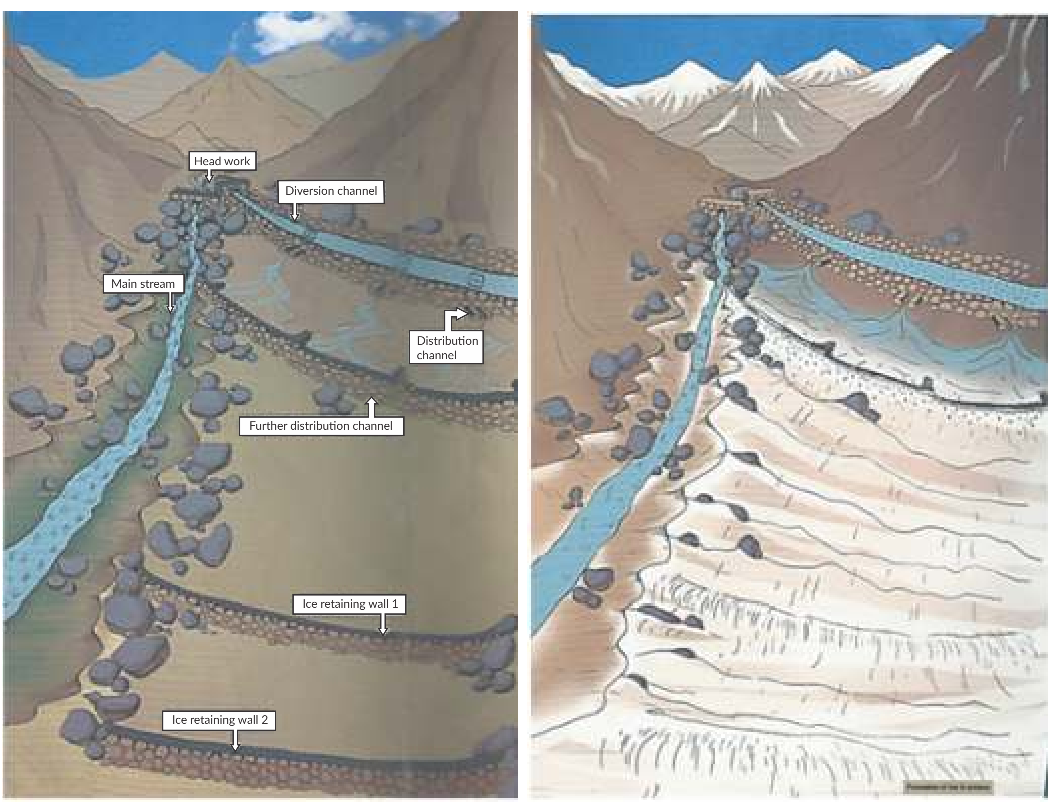

Figure 2: Design, structure and formation of artificial glaciers

2.2 Operation and social cooperation

The construction work is undertaken between May and October. Water collection at the glacier site begins in mid-November at a slow pace. Stabilization of ice occurs within 24 hours and gradually gets converted into a glacier or ice block. The glacier remains in place till end of March when the melting begins with rise in temperature. Compared to natural glaciers, artificial glaciers start melting earlier as they are located at lower altitudes and are exposed to rising temperature sooner. There is almost 1,200–1,700 m altitudinal difference between the locations of natural and artificial glaciers across all the sites. Artificial glaciers are located between the village and natural glacier, at different altitudes, to ensure melting at different times. The glacier located closest to the village melts first and provides irrigation at the crucial sowing time in April. As the temperature rises, the next glacier melts and continues to provide assured irrigation to the fields below.

By the time the artificial glaciers melt completely, the process of high altitude snow melting also starts. Water is stored in reservoir ponds located at different sites in the village. Water distribution is regulated by volunteers appointed by the village community through the existing network of *kuhls* and channels. The active life of an artificial glacier is usually about 4 months (mid-November to mid-April), depending on the length of winter and prevailing temperatures. Under cloudy weather, when the melting slows or stops completely, water in the village reservoir / ponds is used for irrigation.

2.3 Economic impact

Artificial glaciers are located between 3,320 and 4,500 m *above mean sea level* (amsl). These glaciers have augmented the household economy of more than 2,000 families. The cost of constructing an artificial glacier usually ranges between 3 and 10 lakhs; works are usually undertaken as part of the government's watershed development program or the Indian Army's *Sadhbavna* Project. The difficult terrain, difficulty in finding labour and the resultant high cost of transporting material explain the high costs. Artificial glaciers have been around for several years and farmers, in particular, seem extremely happy with the results. Table 1 shows the impact on cropping pattern, productivity and income. There has been a shift from traditionally grown crops to more remunerative crops as well as increase in yield of crops. Both these changes have resulted in roughly 3–4 fold increase in the income of beneficiary farmers. Moreover, they are also generating additional income from livestock rearing through milk and other products due to increased acreage and greater cuttings from fodder. Artificial glaciers have also contributed to the development of pastures for cattle rearing.

The economic feasibility measures were estimated based on the data of five active artificial glaciers out of the total seven surveyed (two AG sites were dysfunctional due to flash floods and were not made operational due to paucity of funds) AG sites which are presented in Table 2. The initial investment at present for creating an artificial glacier comes to be ₹ 13.50 lakhs which may vary depending upon the site specification. The recurring cost on repair and maintenance of structure was found to be roughly ₹ 50,000 per annum per artificial glacier; we assumed this cost would increase by ₹ 20,000 every five years. The project life was assumed to be 15 years. Our analysis shows that investments are economically feasible and substantially lucrative.

2.4 Environmental and social impact

There are several other positive impacts of artificial glaciers. Diversion and slowing down the flow of water

Table 1: Impact on cropping pattern, productivity and income

Crops	Before AG Project		After AG Project		Absolute Change		Percentage Change		Control	Yield Diff. with control
	Area (ha)	Yield (q/ha)	Area (ha)	Yield (q/ha)	Area (ha)	Yield (q/ha)	Area (%)	Yirld (%)	Yield (q/ha)	(q/ha)
Barley	63	18.8	58	21.7	-5	2.9	-7.9	15.5	19.3	2.4
Wheat	353	12.4	335	17.2	-18	4.9	-5.1	39.5	14.2	3.0
Millets	184	2.0	138	2.6	-46	0.6	-25.0	29.0	2.0	0.6
Potato	57	19.5	78	23.0	21	3.5	36.8	18.0	20.0	3.0
Peas	38	31.0	47	37.5	9	6.5	23.7	21.0	33.0	4.5
Vegetables	19	38.5	53	47.0	34	8.5	179.0	22.1	41.0	6.0
Alfa Alfa (fodder)	42	1-2 cutting	57	3-4 cutting	15	-	-	-	-	-
Total	**756**		**766**							

Source: Field Survey (2015)

Table 2: Economic feasibility measures on investment in artificial glaciers

#	Feasibility measure	Value
1.	Benefit Cost Ratio (BCR)	14.65
2.	Net Present Value (NPV)	₹ 36.52 lakhs
3.	Internal Rate of Return (IRR)	152 per cent
4.	Pay Back Period	2 Years 6 months

Note: Discounting Rate = 12 per cent

helps groundwater recharge and although there is no groundwater use for agriculture in the region, enhanced recharge helps in improving the productive discharge of downstream springs. There has been a lot of groundwater development in the main Leh town since last decade to augment the water supply for hotels and other commercial establishments. Artificial glaciers can be used despite low snowfall as water produced at the spring can be frozen at lower altitudes and converted to ice near the village. People save time accessing water and there is a decline in water losses caused by seepage. The summer cropping season gets extended enabling farmers to grow additional crops like potatoes and green peas which fetch them good income.

Ladakh is essentially a peaceful region where different communities co-exist in spite of difficult conditions. However, one main source of dispute is the distribution of water – the scarcest and most valuable natural resource. One important impact of artificial glaciers on social life is the reduced water disputes among neighbours and families due to improved water availability. Expansion of agriculture and increase in local cattle population – both attributable to increased water availability – also means increased availability of farm employment in the village. This has checked the migration of people from project villages.

3. Ice Stupas: Conical Glaciers

3.1 Ice Stupas

The Ice Stupa Project was conceived to overcome the problems of artificial glaciers which require very specific site conditions. The first prototype was constructed at the SEMCOL (Students' Educational and Cultural Movement of Ladakh) Alternative School in Leh. The brain behind this novel technique is Sonam Wangchuk, a local mechanical engineer and founder of SECMOL. The basic idea behind Ice Stupas is to freeze and hold the water that normally would have run-off downstream throughout the winter so that it can be used in the spring time when the fields need it the most during sowing period. Unlike artificial glaciers, ice stupas do not need to be located at high altitude, require very little horizontal space, shading and maintenance.

The prototype was a success and it lasted till mid-May. Encouraged by the results, SEMCOL collaborated with the Phyang Monastry for a full-scale structure that could turn the Phyang desert green. The new structure, implemented in the winter of 2014-15 in Phyang village in Ladakh, was achieved by freezing stream water vertically in the form of ice towers or cones 30 – 50 m in height.

The design and structure of Ice Stupa can broadly be divided into three components: [a] head-works and diversion channel; [b] the main site where conical structure is created; and [c] distribution channels. Among these, about 50 per cent of the project cost is incurred on underground laying of pipes almost two to three feet deep so that the running water does not get frozen until it reaches the glacier site. The length of underground diversion pipe is 2.5 km with a drop in head (difference in height from inlet to outlet) of about 65 m. As water maintains its level, the water piped in from 65m upstream would easily rise close to 60 m through vertical pipes from the ground level at the

Figure 3: Ice Stupa (Left) and a traditional Mud Stupa (Right)

Figure 4: Ice Stupa formation in Phyang desert

glacier site. The site was water proofed with locally available clay so that there is minimum seepage when the stupa starts melting. The base of the site was made dome shaped with a tunnel in which men can move inside for carrying out operations. Sprinklers mounted on the top of pipe make the water fall in small droplets and the frigid wind freezes the droplets as they hit the ground. To speed up the ice formation process, the structure is covered with thorny twigs of sea buckthorn all around. A cone of ice gets built up slowly but steadily (see Figure 4).

3.2 Financing and potential impacts

With the concept proven, the biggest challenge was the cost implication to execute the project. In the past when the people of Ladakh built mud *Stupas* they relied on '*hala*', a system of donating labour based around the monastery. In this digital age, the team raised finances online through Crowd Funding worldwide. Funds to the tune of $ 1,25,000 (₹ 75 lakhs) were raised on the American crowd funding platform Indiegogo and deposited into the official accounts of Phyang Monastery which are being used for greening the Phyang desert through Ice Stupas. A total of 330 contributors from 31 countries across the globe raised $ 125,200 (105 per cent of the original goal) at the end of the campaign (23rd December, 2014). Contributions ranged from $ 5 to $5,000 and above. Out of 330 contributors, 10 donated over $ 5,000 and India accounted for 35 per cent of the contribution, the largest contribution by country. Pan India Paryatan Pvt. Ltd., the group that runs India's largest entertainment theme parks Esselworld and Water Kingdom, matched contributions totalling about $ 47,000 on the crowd-funding site.

As the Ice Stupa Project is in its infancy, 5,000 tree saplings of willow and poplars were planted below the glacial structure on the desert which are watered by the melt water. Initially they want to create greenery in the desert through plantations. The trees command a premium especially Ladakhi poplar and willow as no other wood is locally available in the region. A fully grown poplar with 10 inches diameter or willow tree fetches almost ₹ 7,000. With good care, they attain such size in just six to seven years. Taking survival rate of 90 per cent, the present market value of trees will be about ₹ 2.84 crores; estimated at a discount rate of 10 per cent. The implementing agency is planning to build a cascade of 80 – 90 ice stupas, each about 30 m tall to store one billion litres of water, enough to cover the entire Phyang desert (600 ha) with a plantation of 2 million trees.

Apart from the monetary gains, this will improve the environmental and ecological services in the desert area by turning it green, avi-faunal habitat, green pastures, and carbon sequestration besides improving the livelihoods of the people. If the project turns into success story, it will transform the whole agrarian structure of the cold, arid and barren desert. As the technology of Ice Stupa is not site specific, it can be built in any area of Ladakh where a natural stream flows.

4. Conclusion

In the wake of climate change, as glaciers recede and winters get shorter and warmer, whatever little snowfall is received, melts away quickly. The snow and glacier melt water drains into the river without any use to the farmers for most part of the year and farmers are unable to find any water when it is needed, during the sowing season. Artificial glaciers and ice stupas are high altitude water conservation techniques that can strengthen the climate resilience of communities. Natural glaciers melt slowly in summer and reach villages only by June. Artificial glaciers, on the other hand, start melting in spring, right when the first irrigation requirement called '*Thachus*' (in Ladakhi it means '*germinating water*') is most needed. Table 3 provides a quick comparison between artificial glacier and ice stupa.

The history of artificial glaciers goes back to 13th century A.D. when the news of Genghis Khan and his marauding Mongol army reached what is now northern Pakistan. The people came up with an unlikely means of keeping the army out; according to local legends, they would simply "grow" glaciers across marching armies (Douglas 2008). Whether or not these stories are true, the art of '*glacier grafting*' has been practised for centuries in the mountains of Hindu Kush and Karakoram ranges. It was developed as a way to improve water supplies to villages in valleys where glacial melt water tended to run out before the growing season.

The Aga Khan Rural Support Program (AKRSP), an NGO based in Baltistan, is actively engaged in funding grafting of new glaciers in the region in order to improve water supplies in villages with limited access. Can artificial glaciers help compensate for the disappearance of naturally forming ones?

Table 3: Comparison between artificial glacier and ice stupa

Parameter	Artificial Glacier	Ice Stupa
Location	Altitude range: 3,300 – 4,500 m amsl Site specific, North-facing and shaded	Altitude range: 3,000 – 4,000 m amsl Not site specific
Shape	Horizontal thick ice sheets	Vertical conical shaped structures
Size (approx.)	Length: 300 – 1000 m Width: 70 – 135 m Thickness: 3 – 6 m	Height: 20 m Basal width: 15 m Basal circumference: 45 m
Glacier volume (m^3)	2,00,000 – 3,00,000 m^3	1,500 – 2,000 m^3
Potential water available (million litres)	2,000 – 3,000 million litres	15 – 20 million litres
Potential Area Benefitted (ha)	40 – 140 ha	4 – 8 ha
Potential Number of Beneficiary Households	50 – 350 Households	Common wasteland of Phyang Village
Cost	₹ 13,50,000	₹ 75,000*
Material and Maintenance	Artificial glaciers can be created with locally available material and maintained by the local community.	Most of the material needs to be transported from outside the region; maintenance requires special skills
Impact	Increased and timely water availability for irrigation; soil moisture conservation and groundwater recharge; reduced incidence of water conflicts	Potential impact is to turn the Phyang desert into green area.
Replication	High altitude ecologies	Medium – High altitude ecologies

* The estimated cost of ₹ 75,000 per stupa is based on the proposal to implement 80-100 new ice stupas with US$ 1,00,000 investment although the cost of the prototype was much higher.

Now, as these remote mountain communities come under pressure from population growth and climate change, researchers and development agencies need to take a serious look at restoring and developing the art of glacier grafting to address water problems of these regions. The technique of creating artificial glaciers or ice stupas needs to be replicated in similar geo-climatic regions such as Lahaul & Spiti in Himachal Pradesh, India; Hindu Kush Himalayan range of Pakistan and Afghanistan; and some central Asian countries like Kazakhstan and Kyrgyzstan. The technology can be replicated in areas with features of 4,666 to 5,333 m altitude range; temperature as low as -15 to -20 °C during peak winters; and longer winter periods of four to five months to ensure longer expansion and formation of glaciers.

Water links the climate system with our human ecosystem and should be central to the debate over how to most effectively tackle the climate crisis. Because the climate impacts on water are so widespread, much climate change adaptation translates into water adaptation. By 2025, almost half the global population is projected to live in water stressed areas (Smith 2009). In general, arid and semi-arid regions are predicted to experience significant temperature increases and reduced precipitation. Under these circumstances, it becomes very important to capture and store water so that it can be used for food production. Taking the right steps now, to implement effective water governance that maintains well-functioning watersheds, can increase the resilience of both communities and economies. Sound science together with credible, salient and legitimate local knowledge is important to support the development and implementation of such innovative policies.

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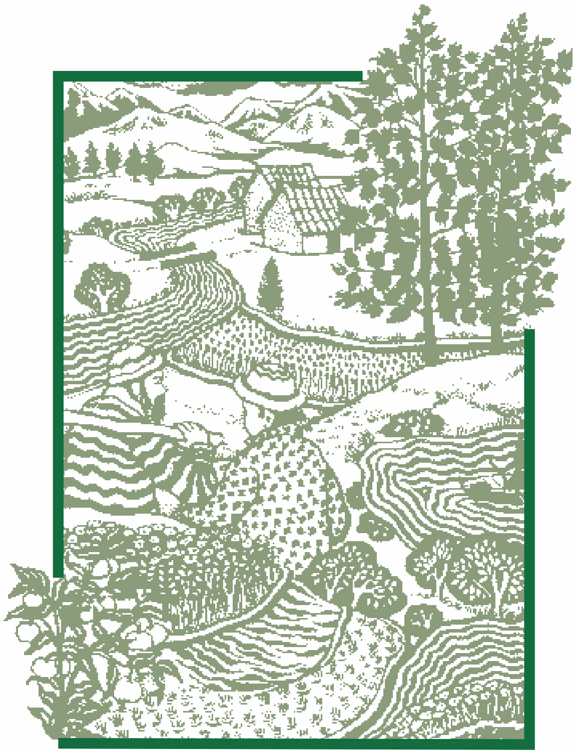

About the IWMI-Tata Program and Water Policy Highlights

The IWMI-Tata Water Policy Program (ITP) was launched in 2000 as a co-equal partnership between the International Water Management Institute (IWMI), Colombo and Sir Ratan Tata Trust (SRTT), Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations. Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the series on Water Policy Highlights and IWMI-Tata Comments.

Water Policy Highlights are pre-publication discussion papers developed primarily as the basis for discussion during ITP's Annual Partners' Meet. The research underlying these Highlights was funded with support from International Water Management Institute (IWMI), Tata Trusts, CGIAR Research Program on Water, Land and Ecosystems (WLE) and CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). However, the Highlights are not externally peer-reviewed and the views expressed are of the author/s alone and not of ITP or any of its funding partners.

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