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Innovations in Water Harvesting Technologies & their Impact in Cold Arid Desert of North-Western Himalaya

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Abstract: As a cold desert with extreme climate and limited precipitation, cold arid desert in North-Western Himalaya struggles to meet its irrigation requirements. In recent years, a historical practice of grafting glaciers and a new innovative technique of building 'ice stupa' have helped communities improve irrigation access and extend the crop calendar. This paper looks at how combining sound science with credible local knowledge is helping people improve climate resilience in geographically disadvantageous areas with harsh environs. Innovative water harvesting technologies need to be up-scaled and refined for greater adaptability and promises great hope for similar geo-climatic regions.

Key words: Water harvesting technology · Cold arid · North-Western Himalaya · Climate Change · agriculture · India

INTRODCUTION

Situated in the northern extremity of India, Ladakh occupies a unique niche - physiographically, climatically and culturally. A cold desert, the region is characterized by lofty ranges, mountain rock-walls, bare ridges, glaciers and snow fields. Geographically, the Ladakh region in Jammu and Kashmir state lies in the high altitude ranges of northern most tip of the Asian sub-continent, between Karakoram and greater Himalayan ranges, interwoven with nude and rugged mountains extending from 32°–15' to 36°–0' N latitude and 75°–15' to 80°–10' E longitude, covering an area of 96,701 km^2 of which 27,555 km^2 is with Pakistan and China (Annexure 1). Meteorologically, it comes under cold arid zone. The cold arid occupies 16% of earths land mass which are usually confined to high altitude and circumpolar region [1]. India accounts for 3.87 lakh km^2 arid zone of which 27.8% lies in cold region of Western Himalaya and rest is under hot arid of Western Gangetic plains and Peninsular India [2,3].

Ladakh region, consisting of Leh and Kargil districts, lies in the high altitude range of North-Western Himalaya. Western Himalaya exhibit diverse topographic and climatic features and amongst these cold arid is almost fragile, inaccessible and marginalized with unique socio-economic and cultural issues. The aridity and extreme coldness are coupled in the region in such a manner that it gives rise to new environment that requires specific treatment with a different approach. The region has highest average elevation dotted with deep gorges, deserts and plateaus. Elevation ranges from more than 2,400–8,500 m. Soils of the Ladakh region are coarse textured, shallow and sandy, with high permeability and low water holding capacity. The region is snow-clad for almost 7–8 months, the remaining being the only 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 7 cm, making it one of the world's highest cold deserts. Temperatures drop to minus 45 °C in winters and hover within the range of 10–30 °C during summer.

Despite hostile conditions, the region is inhabited for centuries and its people have learnt to survive there by establishing a synergistic relationship with their environment. The dynamics of transformation (or persistence) of land-use practices and patterns in peripheral high mountain regions strongly depend on the interplay of local environmental knowledge and external

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development interventions. Beyond ethnic and cultural particularities, local communities in the Himalayan region help secure their livelihoods by pursuing altitudinal diversification across agro-ecological zones and by decreasing the threat that natural hazards pose to any of these environmental resources [4-7]

Although livelihood strategies have diversified, agrarian land use remains the economic mainstay of the local population [8]. Adequate crop production therefore assumes a central role in the lives of these people, making the availability of irrigation water indispensable. The chief components of that resource in Ladakh are meltwater from glaciers and seasonal snow cover. However, seasonal melting of glaciers occurs quite late because of the region's high equilibrium line altitude (climatic snow line), which delays the availability of glacial meltwater until June. This seasonal water scarcity makes it essential to provide supplementary irrigation in order to take advantage of the complete growing season.

Life is never easy for the hard working people of Ladakh region and is severely constrained by the perpetual shortage of water. At the altitudes of more than 4,267 m, the severe climate and inhospitable terrain means Ladakh's peasants are able to plant and harvest only a single crop each year - wheat, barley or vegetables. It seldom rains in the area, so farmers rely heavily on natural glacier melt to irrigate the crops. Hundreds of glacier melt streams make three great rivers, the Indus, the Zanskar and the Shayok in Ladakh that finally make their way into the ocean before passing through the Pakistan. Only 10–15 per cent agriculture farming is benefited out of Indus and Shayok in Ladakh, with the rest 85 per cent of farming irrigation entirely dependent on snow-melt streams and traditional water management system of all the watershed areas in the cold arid desert of Ladakh that are prevalent and practiced for centuries by the farmers. This system of water distribution during the farming season is strictly followed by the peasants at their respective villages and is recorded very minutely in revenue records popularly known as Rewaj-e-Abpashi (customs of irrigation) recorded in between 1909 and 1911 having time table for each and every distribution channel in every village. A strict implementation of the system is ensured through a group of Churpon (*Mir-Abs*/water-man), elected amongst the farmers by turn each year and these Churpons are highly empowered to penalize those who violate the system. Therefore, there has been least opportunity for extension of land holdings as there is no scope to share the water for new areas to bring under plantation or vegetation.

Climate Change – Impact on Glaciers and Water Availability: More than one sixth of the world's population lives in glacierfed and snowfed water basins [9]. As global temperatures are increasing, snow-cover is decreasing in most regions of the world. There is a melt-off and mass loss for the majority of the world's glaciers and ice caps that changes the hydrology of glacierfed water basins [10]. As glaciers melt due to global warming, river discharges for glacierfed rivers will increase in the short term but decrease over the next few decades as ice storage gradually diminishes [11]. The climate of the Himalayas is highly variable because its wide range of geographical factors such as elevation and rain shadow effects that contribute to variations in temperature and precipitation [12].

The Himalayan mountain range is the most extensive and tallest mountainous area on Earth and stretches across the border of the Indian and Eurasian tectonic plates with a length of 2,400 km and a width of 150-400 km [13]. The Himalayan glaciers support all the rivers of Asia with perennial stream flow and are of large importance for high altitude regions as they affect the climate and hydrological cycle [14]. The region is often called "The water-tower of Asia" as it is the source of the 10 major rivers of the Asian land mass: Indus, Ganges, Mekong, Yangtze, Yellow River, Amu Darya, Brahmaputra, Irrawaddy, Salween and Tarim [15, 10]. These rivers provide water for about 1.3 billion people; a population that is likely to increase given that the global population is projected to increase by approximately 3 billion by 2050 [16].

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 [13]. Glacier and ice cover some 17 per cent of the greater Himalayan region, a total area of nearly 1,13,000 km^2, the largest area covered by glaciers and permafrost outside the polar region. With glacier coverage of 33,000 km^2, the region is aptly called the 'Water Tower of Asia' as it provides around 8.6×10^6 million cubic meters of water annually [17, 18]. It is the source of nine largest rivers in Asia, whose basins are home to over 1.3 billion people. Climate change has impacted the glacial ecosystem tremendously. Sixty seven per cent of glaciers are retreating at a startling rate in the Himalaya and major causal factor has been identified as climate change [19, 20, 21, 22, 23, 24]. Glacial melt will affect freshwater flows with dramatic adverse effects on drinking water supply, biodiversity, hydropower, industry, agriculture and others with far reaching implications on the people of region. The analysis of meteorological time series data (1973-2008) by Shaheen *et al*. (2013) showed rising trend of minimum temperature of the order of nearly 1 °C for all the winter months and 0.7 °C for summer months at Leh, Ladakh [25]. One degree increase in winter temperature has serious implications on glacial formation and water security of the Ladakh region, in particular and the Indus basin, in general. The snowfall which accounts for 70 per cent of total precipitation shows a declining trend by about 4 mm and rainfall in the summer season which contributes 30 per cent to total precipitation has declined by 3 mm over the time period [25].

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. The most critical factors for extension of glaciers are extremely low temperatures complimented by heavy snowfall during peak winters, which in earlier days was favourable. However, over the past 36 years, due to changing temperature and precipitation, small glaciers in the region are retreating at a much faster pace than imagined, especially since the rising temperature trend is sharper in min temp of winter months and the declining trend in precipitation is sharper for the winter months. The winter precipitation is of utmost importance as 70 per cent of the total precipitation (in the form of snowfall) over the entire year takes place in the winter months.

The Issues of Agrarian Sustenance: Ladakh is a highly elevated, cold arid desert where people live at altitudes exceeding 4,000 m above mean sea level. Spread over an area of about 9.9 million hectares, the region has a population of about 2,74,289 (2011 Census) of which nearly 85 % depends on agriculture. Situated in the rain shadow region of the upper Himalayas, Ladakh receives an annual average rainfall of 50 mm between May and July. Subsistence farming on very small holdings (average land holdings 0.72 ha with 80 % holdings smaller than one ha) with nominal animal husbandry and a limited trading activity (Annexure 1), is still the mainstay of a major chunk of the population, relying on hard work and scarce local natural resources, to meet their everyday need. Hardly anything grows in Ladakh naturally; everything has to be cultivated using irrigation techniques. The key to cultivation in Ladakh is the intelligent use of water. Ladakh has abundant sunlight and good soil but without water it is a vast barren desert. Nearly 68 per cent of the total land lies 5,000 m above mean sea level and is virtually unfit for vegetation and human life. Agricultural operations are confined to areas below 4,500 m in altitudes with the growing season restricted to less than 6 months a year.

Dry land cultivation is not possible in Ladakh. The entire 19,967 ha of cultivable land depends on assured irrigation from the glacial melt water through long, rocky, sandy and winding streams from the upper mountain reaches. 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. It is really water from melted snow that sustains life and most people live along glaciers and snow-melt water courses. The agriculture season in Ladakh begins in April with the melting of snow in fields. The melting of snow is often late, delaying the availability of water for irrigation and the sowing of crops, thereby, adversely affecting the production. The summer season in the region is of short span and mono-cultured. The farmers need to cultivate the crops like wheat, barley, peas, potatoes, alfa alfa, etc., at the proper time to allow it to mature within limited short summer season. The agriculture season commences in the month of April–May, while the process of snow and glacier melting at high altitude begins around end- June. During the rest of the year, from August to April, very little water comes down the streams, as temperatures at the high mountain peaks do not allow snow to melt. This delays the process of seed sowing, which affects the crop productivity adversely. 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 not adequate enough to facilitate the snow/glacier melting process. The potential for improving agricultural production is, thus, restricted to the traditional turn of water sharing and distribution system prevalent throughout the year.

Problem Statement: In order to get produce from the soil, the traditional technologies adopted and innovated through centuries by the communities revolve round water management. Be it the creation of artificial glaciers to augment the first irrigation in April-May when seeds are sown or newly innovated technique of forming *ice stupa* to make barren lands green as well or formation of *Zhongs* for water conservation. Ladakh traditional framing system has been included in the FAO list of possible "Globally Important Agriculture Heritage Systems

(GIAHS)", worthy of being preserved and conserved. However, globalization and climate change had severely impacted and marks are very well significant in socio-economic and environment discourse of the region. In order to adapt and mitigate the impacts of such global changes, the region is experimenting with new techniques based on traditional knowledge blended with modern science centring on water management to sustain the livelihoods in harsh environs. What are the water management issues, challenges and options in the region and how they are being managed? What are present technologies available and how it is catering the needs of people, their outreach, efficiency and effectiveness; and whether these technologies are upscable? The present study has been attempted to make a systematic enquiry which will through light on the issues, challenges and options of water management issues in the cold arid desert of north-western Himalayan region. The main objective of the study is to understand the hydrological, economic and environmental aspects of artificial glaciers and ice stupas in Ladakh region in the wake of climate change.

Methodology: The study was undertaken in the Leh district of Ladakh region where the people have devised the water harvesting structures to augment the water supply during sowing period. The study areas within Leh district are the artificial glacier sites and the villages irrigated/benefitted by this technology. Apart from artificial glaciers, one more area (Phyang village) was undertaken to study the newly created *Ice Stupas*. The study focuses on the technological aspect of the artificial glaciers and / or *Ice Stupas*, its design, structure, engineering, hydrological and cost implications. The second part of the study tries to assess the impact of the artificial glacier technology on the beneficiaries in terms of improved livelihood from the farming, livestock, pastures etc. The study also tries to evaluate the non-market value of the water harvesting structures in terms of environmental and social benefits.

The present study mainly focussed on participatory rural appraisal (PRA) and focused group discussions (FGDs) with the farmers and village leaders (Sarpanchs and Panchs) in order to assess the feasibility and relevance of creating artificial glaciers from peoples' perspective rather than the implementing agency. Furthermore, they were mainly evaluated to see the impact of these water harvesting structures on their livelihoods in terms of farming and allied activities. A total of 7 artificial glacier (AG) sites were surveyed for detailed analysis on the proposed areas of research. Along with these artificial glacier sites, the villages/hamlets were surveyed to assess the overall impact. The study pertains to year 2015 with field surveys conducted in the months of September-October, 2015.

Genesis and purpose of creating Artificial Glaciers: The traditional ponds, reservoirs and khuls existing in many villages are in a dilapidated condition, which cannot store the melting water for long time. A lot of efforts were put up by different agencies to find out the possibilities to make these reservoir/ponds more spacious, efficient and strong. The *kuhl* and distributaries were also repaired to improve the efficiency, however, the main problem of making water available to farmers during the spring season still persist. The need was, therefore, felt to develop a technique that will ensure the water availability to farmers during the critical stage of seed sowing period (April–May). Chewang Norphel, a retired civil engineer and National Prize Award winner, known to his men as the 'ice man', came with a solution with an innovative technique of creating artificial glaciers in the region. 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 the momentum. This inspired Norphel to make the artificial glacier. The first artificial glacier was experimented in 1987 at Phuktse Pho village in Leh district and was spread to other villages after establishing its successful performance. Till now, ten artificial glaciers have been created purely on a community based approach, keeping in view the farmers demand with a bottom up approach and peoples cooperation.

Ladakh, known as the land of mountain passes and majestic glaciers—glaciers that feed some of Asia's largest rivers, thereby, sustaining the livelihoods of millions of people. However, glaciers are now retreating by some 50 ft every year and Ladakh is no exception. There are visible marks of climate change impact on the region. Over the years, winters are getting shorter, there is less snowfall and whatever snow is there melts rapidly leaving the region before it can be used in the sowing season. The main purpose and need felt for creating of artificial glaciers was to make water available at the beginning of sowing time in the month of April when there is no water. The artificial glaciers are created at the top of the villages below the foothills on shady side. These glaciers are created with the objectives to ensure the availability of water during early spring season for cultivation; to enhance the crop productivity by making water available in adequate quantity and in time; to bring waste lands, uncultivated land under productive activities; to improve the cropping pattern of the farmers; to prevent the wastage of scarce water and to mobilize farmers participation in the management of artificial glacier formation and components of the irrigation system.

Design and structure of Artificial Glacier: The artificial glacier is an intricate network of water channels and check dams along the upper slope of the village valley. The technology for creating artificial glaciers consists of three main components, i.e., headworks or diversion channels, main artificial glacier structure and distribution network/channels. The mainstream water is diverted towards a shady area by constructing a long channel created with the help of dry stonewall across the hill slopes to the artificial glacier site. The length, breadth and depth of channel vary with the slope of the hill as well as an estimated discharge of the stream. The channel is protected by dry stone retaining and breast wall and suitable bed grade to smoothen the flow of water to a canal. The stone wall is erected with the help of locally available stone and chassed with organic manure mixed with soft soil. The organic manure and soil help to establish the stone wall with the help of naturally mixed shrubs and plant materials to strengthen the wall. No other concreting or cementing material is used to strengthen the wall. This minimizes the cost of construction so also there is minimum danger of it getting washed away as there is no torrential rain.

The process of artificial glacier formation and site selection envisages some basic pre-requisites. First, the collection of discharge data from the main stream is done to ascertain whether water remains throughout the winter. After this, the selection of site for formation of the artificial glacier is based on that it should be on the north side of the hill under shade which prevent/minimize the effect of direct exposure of the glacier to sun shine as well as smoothening the process of glacier formation. Secondly, it should not be located on a steep slope but preferably in plain area with 20–30 slope gradients so that along with losing momentum, water gets frozen into ice sheets. Thirdly, it should be at a lower altitude to facilitate the process of early melting, preferably at 3,3500–4,267 m; and, finally, it should be near to a village so as to make ice melt water available within shortest distances from the cultivated fields and minimize seepage losses and delivery time.

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 built of dry stone masonry in crate wire on the lower side of diversion channel at the glacier formation site. Length of proposed glacier and number of barrier bunds depends upon the slope at the site. Lesser the slope more will be the length and less number of bunds, with more inter-bund intervals and vice versa. If the section of the stream is very wide with a mild slope, then the dry stone masonry bund in crate wire across the stream are constructed in a series parallel to each other. The number and dimension of ice retaining bunds depends upon the water discharge available in the main stream during peak winter. In the month of November, when winter starts, some wild grasses locally available are needed to be put on the base of the dry bund to plug the void which helps in freezing the water instantly (Fig. 1).

If the section of stream is narrow with a steep grade, then it needs to be diverted to a shady area by constructing a gravitational channel with a bed grade 1 in 30. When it reaches at the glacier site, the bed grade should be gradually reduced, say up to 1 in 50, so that water can flow through various small outlets. The water flowing through these small outlets being in very small quantity freezes instantly. Dry stone masonry in crate wire needs to be constructed parallel to the channel in series at a distance of 10–30 m according to the nature of slope of terrain. Steeper the terrain, lesser the distance and lesser the slope more is the distance between the bunds. The process of ice formation continues for 3–4 months and a huge reserve of ice accumulates on the mountain slope, aptly termed as ‘artificial glacier’.

Structural Operations and Social Cooperation: The work for creation of the structure is taken up in between May and October. Water collection at the glacier site begins in mid-November at a slow pace. Freezing of water begins at zero degrees Celsius. Stabilization of ice occurs within 24 hour and, thus, gets converted into a glacier or ice block. The glacier remains in place till end of March when the process of melting begins with the rise in temperature. Artificial glaciers start melting earlier compared to natural glaciers as the former are located at lower altitudes and exposed to rising temperature early. There is almost 1,200–1,700 m altitudinal difference between the locations of natural and artificial glaciers across all the sites. In the beginning of April, the temperature in the Leh plains is in the range of 9–10 °C, whereas, at high altitudes where natural glaciers are located, temperature remains confined

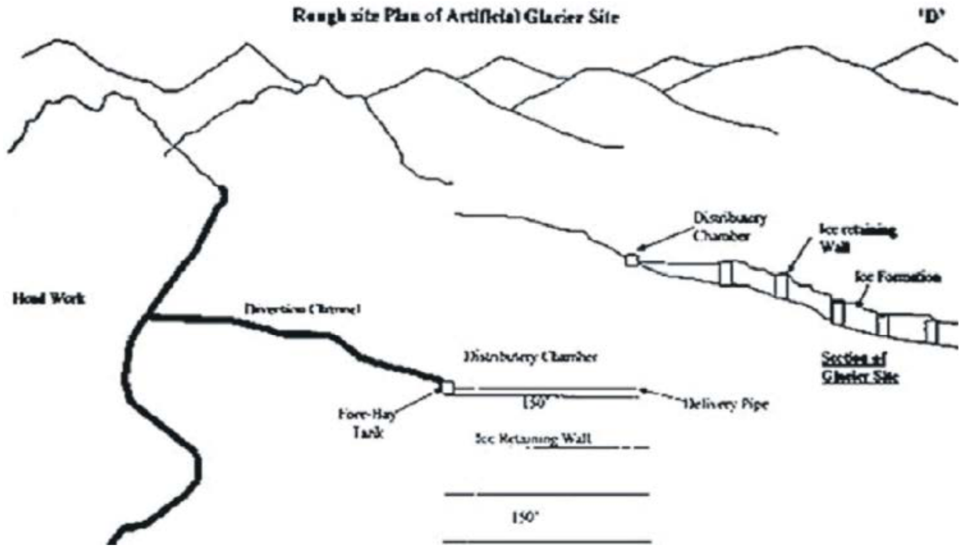


Fig. 1: Rough site plan of artificial glacier

to -10 °C. The artificial glaciers are located between the village and the natural glacier at different altitudes so as to ensure melting at different times. The artificial glacier located closest to the village/or lowest altitude melts first and provides irrigation water at the crucial sowing time in April. As the temperature increases, the nest glacier which is located at a higher altitude then melts and process of melting at different times continues to provide assured irrigation to the fields below. The stepwise procedure for freezing/formation of artificial glacier is as follows and same has been depicted in Figure 2 and 3.

- Stream water at different altitudes is diverted to shaded area of the hill, facing north side, where winter sun is blocked by a ridge or a mountain slope.
- At the start of winter (usually November), the diverted water is made to flow onto sloping hill face through appropriately designed distribution channels/outlets.
- At regular intervals, stone embankments are built which impede the flow of water making shallow pools.
- The process of ice formation (icings) continues for 3-4 winter months and a huge reservoir of ice accumulates on the mountain slope, aptly termed as 'artificial glacier'.

The melting of the glacier depends upon the size and temperature; however, the benefit is that when the artificial glacier melts completely and flows in full swing, the process of high altitude snow melting starts, which slowly streams into the reservoir. Melting water from glacier is stored in the reservoir ponds located at different sites in the village. Water distribution is regulated by the volunteers appointed by the village community through existing network of *kuhls* and channels. The active life of an artificial glacier is usually about 4 months (mid-November to mid-April), however, it will depend upon the length of winter and prevailing temperature. During cloudy weather, when the snow melting process gets slowed or stopped completely, then the water in the village reservoir ponds is used for irrigation.

Technical Aspects: Under the technical requirement, priority is given to various aspects such as direction of the village, water availability in the stream during peak winters, location, etc.

- Direction of the village:- All villages where artificial glaciers have been constructed are south facing villages (on the south of the Indus River) so as to ensure proper formation during winters and its timely melting during the spring season, e.g., Saboo, Igoo, Sakti, etc.
- Location/proximity to the village:- The location of the artificial glacier must be as close as possible to the village so that the artificial glacier melts quicker as compared to the natural glacier and reaches the adjoining village at the crucial time i.e. sowing period in April/May.

Out of the seven artificial glacier sites selected for study (Table 1), two were inactive due to flash floods in 2010 whereby the structures had got washed away.

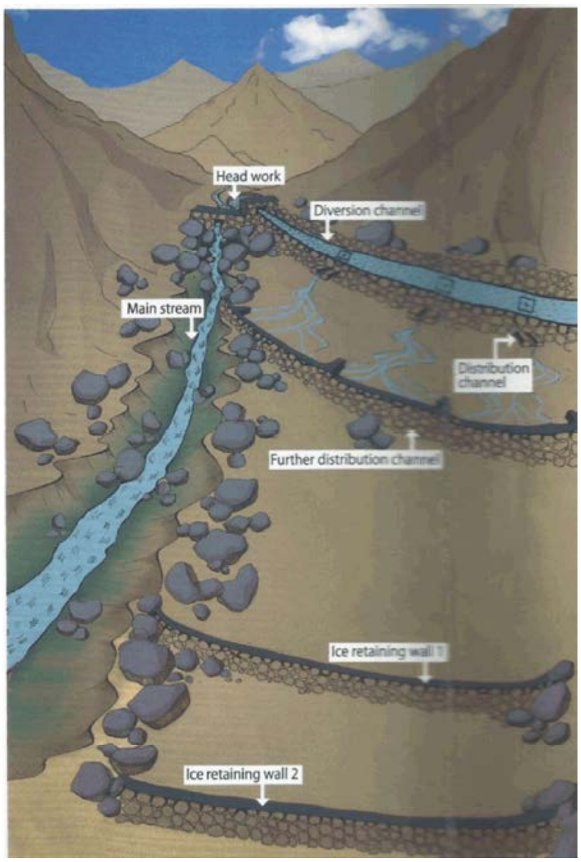


Fig. 2: Design and structure

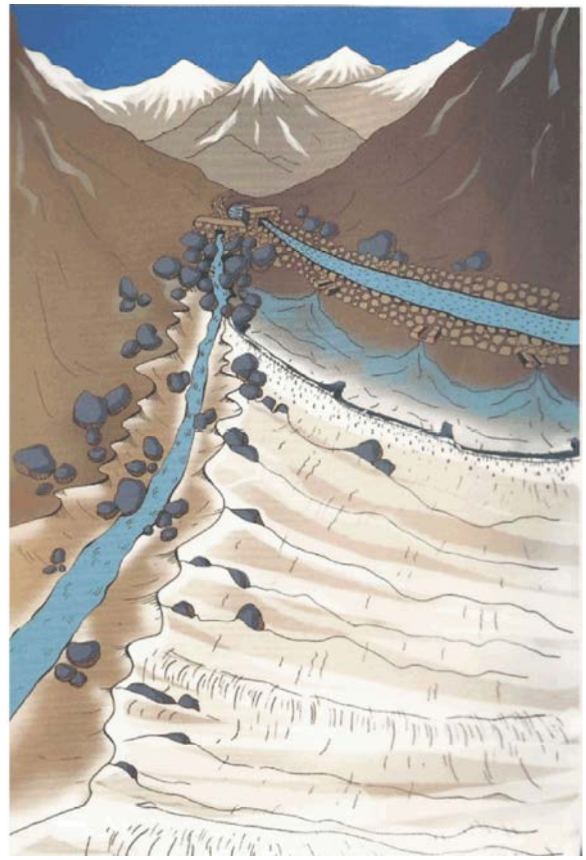


Fig. 3: Ice formation at AG site

Pic. 1: Artificial glacier at 3,900 m (about 12,800 ft), located above the village of Nang, Ladakh. The cascade is composed of a series of loose masonry walls ranging in height from 2 to 3m, which help freeze water for storage

Artificial Glacier

Norphel on Artificial Glacier

Pic. 2: Community participation for check dams at Igoo village

Table 1: Particulars of selected artificial glaciers

Particulars	Artificial Glacier Sites: *Phuktse*	*Nang*	*Saboo*	*Stakmo*	*Igoo*	*Changla*	*Stongde*
Altitude (m)	4114	3886	4389	3931	4206	4500	3320
Year of creation	1987	2004	2001	2005	2008-2013	2004	2013-14
No. of villages/hamlets catered	3	1	2	1	5	02	2
No. of families benefited	193	74	259	300	238	723	325
Population	1187	334	1233	1471	1103	7940	1327
Cultivable area including plantation (ha)	89	53	133	328	151	463	135
Establishment and Rebuilding costs	1.35 Lacs in 1987 by RDA, 2.7 lacs in 2004-06 by WDP, 2.36 lacs in 2013-14 by RBS	1.5 lacs, 7 Lacs	5.94	9.35	16 lacs in 2008, 1.30 lacs in 2013 to rebuild and 3.5 lacs for drainage work by Tata-trust	1.15 lacs	17.85 Lacs
Programme/ Funding agency/ Organization involved	RDA, LNP, WDP, RBS	WDP/RDA	WDP/RDA	Sadhbavna (Indian Army), LNP	Sadhbavna (Indian Army), LNP & Tata-Trust	WDP, LNP	VSI through
Chewang Norphel							
Water source	Stream	Stream	Stream	Stream	Stream	Stream	Stream
Status	Active	Active	Inactive	Inactive	Active	Active	Active

Source: Field Survey (2015)

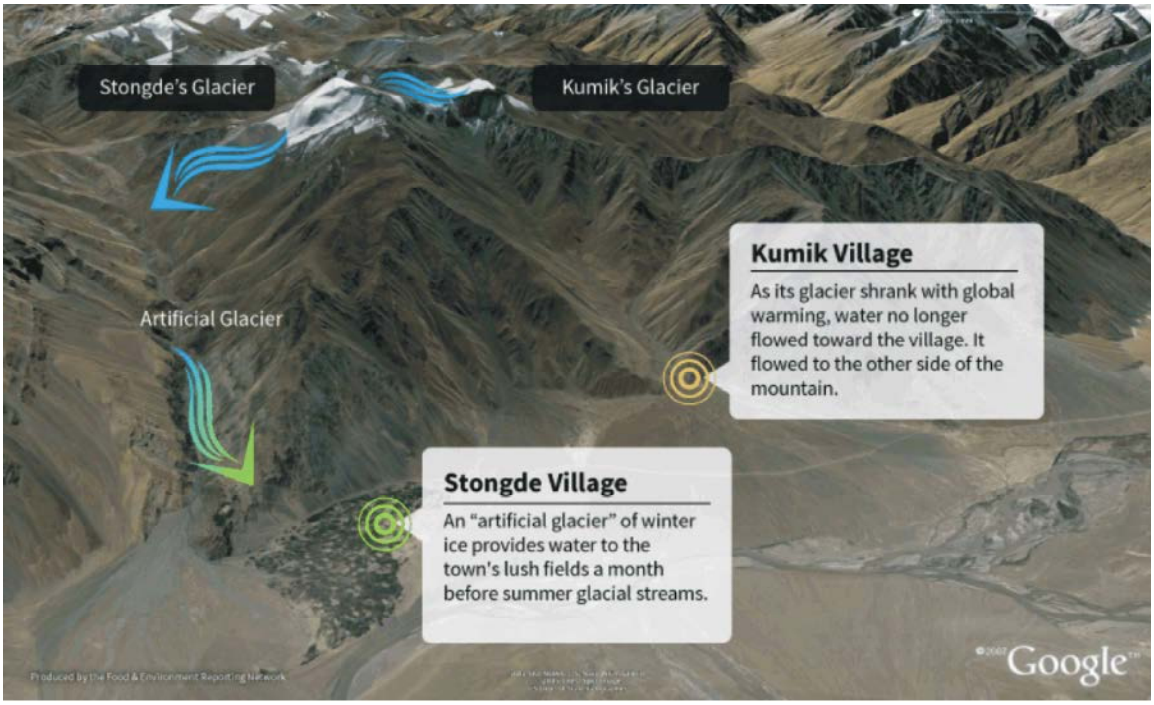
Pic. 3: GIS Imagery depicting the altitudinal difference between natural glaciers and artificial glacier created in Nang.

The first artificial glacier created was at Phuktse in year 1987 by Norphel when he was working in Rural Development Department at a cost of Rs 1.35 lacs. Later on in 2004-06, an amount of Rs 2.70 lacs was spent on its rebuilding and maintenance under Watershed Development Program with LNP (Leh Nutrition Project) as implementing agency. The damages incurred due to flash floods in 2010, it was again rebuild with funding to the tune of Rs. 2.36 lacs from RBS (Royal Bank of Scotland) in 2013-14.

The Igoo Artificial glacier has been created recently in year 2013 with the help of LNP (implementing agency) and Tata trust (funding agency) for almost Rs 5 Lacs by creating 23 walls or check dams of boulders locally available across the gorge slope. The glacier serves water to five hamlets. Each household of the hamlet participated for the construction of the artificial glacier with at least one member from the family for 5 days on an average. Around 205 people from all the hamlets gathered for the construction of the artificial glacier.

The work for artificial glacier at Nang was executed in year 2004 by the LNP under WSDP Program with an investment of Rs 1.5 lacs including the headworks. Later on the project was strengthened by DST funding (Rs 7 Lacs). It has a total wall length of 1001 feet. The green lined area represents the agricultural fields of Nang village and at the end on right side between the gorges is the artificial glacier site which has been shaded with blue. There is an altitudinal difference of about 1641 metres between the natural glaciers (5527 m amsl) and artificial glacier (3886 m amsl). It is this altitudinal difference which makes the melt water available earlier (20-40 days) from artificial glaciers than the natural glaciers and makes a huge difference in setting the cropping calendar for a region where the summers are very short and limited crop growing period.

The Changla represents the world's highest watershed development project. It was undertaken in 2004 with a meagre amount of one lac rupees by the LNP under WSDP at an altitude of about 5182 metres. The flowing water is being tamed in form of glacier by using big boulders to ensure that the water after a little snow that Ladakh receives is not lost towards China but provides irrigation and drinking water for the villages on the Indian side. Presently, two villages viz., Sakti and Chemre are getting benefitted by this Artificial Glacier Project. Chemre is just downstream of Sakti village in the same watershed and every 7th day, the residents of Sakti (upstream village) forego water, letting it run down to feed Chemre village for a 36 hour period as an obligation to the downstream village.



Pic. 4: Google earth imagery showing Kumik and Stongde and the glaciers on which they have depended for water as well as the site of artificial glacier.

Stongde is the name of village in Zanskar valley of Kargil district. The village lies almost 9 kms from Padum, headquarter of the Zanskar Sub-Division. Situated on a bench between rugged mountainside and the east bank of the Zanskar River, Stongde is one of Central Zanskar's larger settlements. The village consists of 6 hamlets (Peyu, Tetsa, Tang, Trodong, Laru and Tama) and together with irrigated land occupies an area of around 135 ha. In the summer of 1998, for the first time, the stream that ran through Kumik (neighbouring village of Stongde) dried up completely due to climate change as glaciers located above the Kumik village had receded significantly. There is a clear contrast of green landscape for Stongde village with water source secured through creation of artificial glacier and the barren desert on the side of Kumik village where the stream is running dry from last several years. Many of the household have got relocated and better to call as a typical case of climate refugees.

It was during the summer of 2013, when people from the Stongde village approached Chewang Norphel to guide the people in creating necessary structure

for artificial glacier. The work was executed during 2013-14 with funding from Village Studies Institute of some European Nation. Three artificial glacier structures were created along the gorge in a continuum with plans to create further two more. These water harvesting structures have given a new lease of life to the people of Stongde which were threatened by the fate of neighbouring Kumik village.

Impact of Technology: For any technology to sustain, it should be socially, environmentally and economically viable. An impact assessment of the technology was undertaken to examine the change on the agrarian economy of the beneficiaries besides knowing its social and environmental impact. Usually, for impact assessment studies in case of irrigation projects are done by adopting with and without and ex-ante and ex-post scenarios. In this case, the impact of artificial glacier technology was assessed by applying ex-ante and ex-post (before-after) method as well as taking a control village with same physiography, agro-climatic and soil conditions. In order to estimate the additional benefits accrued due to technology, seven artificial glacier sites which were selected for complete assessment. The particulars of these seven created artificial glaciers are depicted in Table 1.

The positioning of these artificial glaciers is in the range of 3,320–4,500 m amsl. These glaciers have augmented the household economy of almost 2112 families with a population of 14,595. The cost for creation of these glaciers usually range from 3 to 10 lakhs and were funded under the government's watershed development

Table 2: Impact on cropping pattern, productivity and income

	Before AG Project		After AG Project		Absolute Change		Percentage Change		Control	Yield Diff. with control
Crops	Area (ha)	Yield (q/ha)	Area (ha)	Yield (q/ha)	Area (ha)	Yield (q/ha)	Area	Yield	Yield (q/ha)	(q/ha)
Barley	63	18.75	58	21.65	-5	2.9	-7.94	15.47	19.25	2.40
Wheat	353	12.35	335	17.23	-18	4.88	-5.10	39.51	14.15	3.08
Millets	184	2	138	2.58	-46	0.58	-25.00	29.00	2	0.58
Potato	57	19.5	78	23	21	3.5	36.84	17.95	20	3.00
Peas	38	31	47	37.5	9	6.5	23.68	20.97	33	4.50
Vegetables	19	38.5	53	47	34	8.5	178.95	22.08	41	6.00
Alfa Alfa	42	1-2 cutting	57	3-4 cutting	15	-	-	-	-	-
Total	756		766							

Source: Field Survey (2015)

Table 3: Economic feasibility measures on investment in artificial glaciers

S. No.	Feasibility measure	Value
1.	Benefit Cost Ratio (BCR)	14.65
2.	Net Present Value (NPV)	Rs. 36.52 Lacs
3.	Internal Rate of Return (IRR)	152%
4.	Pay Back Period	2 Years 6 months

Note: Discounting Rate= 12%

programmes as well as under Indian Army's Sadhbavna Project. Due to difficult terrain and high altitude compounded with non-availability of labour, the cost of transporting the materials is very high. The artificial glacier has been operating in the area for the past so many years and is performing with great success. Farmers, in particular, are extremely happy with the positive results of the technology. Water from the artificial glacier melts much earlier in the year than the natural glacier. The process is able to take place in spring, whereas, with the natural glacier water melting, cultivation would take place 20–30 days later, thereby, adversely affecting the crop yield. The wastage of water from the winter can later be used for irrigation. In this region, only one crop can be taken, after which the water goes to waste. With an adequate quantity of water available at this earlier stage, more areas can benefit from the production of food crops, vegetables, fodder crops, trees, willows, poplars, etc.

As is evident from the Table 2, there has been shift in area from traditionally grown crops to more remunerative crops as well as in the yield of these crops. Both of these changes (area shift as well as increased yield) have resulted in 3–4 times increase in the income of the farmers of these villages getting benefited out of this technology. Moreover, they are also generating more income from the livestock rearing through milk and other products due to more acreage as well as increased number of cuttings from alfa alfa fodder crop. It has also helped in developing pastures for cattle rearing, which is an important livelihood asset of the region.

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 3 and its cash flow has been depicted in Annexure-II. The initial investment at present for creating an artificial glacier comes to be Rs. 13.50 Lacs which may vary depending upon the site specification. The recurring cost on repair and maintenance of structure was found to be Rs. 50,000 per annum per artificial glacier and same was increased by Rs 20,000 amount after every five year span due to cost escalations. The economic feasibility measures were estimated based on the investment and operational/recurring expenses and the incremental income generated out of this investment. The project life was assumed to last for 15 years. The viability measures as arrived in Table 3 are highly feasible for investment on artificial glaciers.

There is environmental and social impact of this technology too in the positive direction. It has helped to increase the ground water recharging in the area as the existing springs in the village produce more water. Though there is no groundwater use for agriculture in the region but it helped in increasing the productive discharge of springs down the stream as observed by the people of the villages benefited out of this technology as well as the implementing agency. However, there has been huge groundwater development in the main Leh town from last decade to augment the water supply for hotels and other commercial establishments. The artificial glacier can be used despite low snowfall, as water produced at the spring can be frozen at lower altitudes and converted to ice within the vicinity of the village. With the artificial glacier being so near to the villages, people save time accessing water and there is a decrease in loss of water due to seepage. The summer season now gets extended since water is available from April which has enabled farmers to grow additional crops like potatoes and green peas in addition to other vegetables, which fetch them good income. There is increase in availability of labour man-days as farmers now get relatively more employment on their fields and has, thereby, checked the emigration of people from these villages. Furthermore, due to adequate and timely availability of water, it has reduced the water sharing disputes among the farmers and has brought social cohesion in the project villages.

Apart from the Ladakh region, Chewang Norphel gave guidance to a village namely Keber in Spiti valley of Himachal Pradesh for creating artificial glacier which was funded by HP govt. Three hamlets have been covered under this project.

Farmers Perspectives: The project on artificial glaciers has been operating in the region since last so many years and farmers in particular have given some positive feedback regarding its impacts. These can be classified into three:

Economic Benefits:

- By provision of timely and adequate irrigation water due to artificial glacier to the barley and wheat fields as well as other cash crops, there is overall rise in agricultural productivity which contributes to increased cash income for farmers.
- Due to availability of water at early spring time, farmers are able to harvest two crops in a year as compared to traditional single harvest. This double harvest again enabled farmers to generate additional income, e.g. Alfalfa fodder crop gives now 3-4 cuttings instead of 1-2 cuttings before the project.
- Due to the additional water made available by the artificial glaciers, villagers are able to increase the number of tree plantations. Trees are a major source of income as the twigs/branches and the main trunk is mainly used in constructing houses (roof and wood floor) as building material.
- Increased availability of water has also led to pasture development in the villages, creating conducive conditions for cattle rearing, hence an additional source of income from dairy products like milk, curd, etc.

Environmental Benefits: The artificial glaciers have a range created a range of environmental benefits as perceived by farmers.

- Channels that are diverted in the shady area to slow down the water, helps to reduce the surface runoff thereby recharging underground aquifers and increasing the underground water table. Water discharge from natural springs (locally known as 'chumiks') has increased as a result of the increased water table.
- Because of the artificial glaciers, the total agricultural land holdings have significantly increased thereby extending the green belt cover.
- The simple technique of artificial glaciers also contributes in soil moisture conservation and humidity which is responsible for creating conducive conditions for plantations and promoting vegetative growth.
- An increase in cattle population leads to increased use of animal dung as manure in agricultural fields rather than chemical fertilizers.
- Restoring ecological balance by harnessing, conserving and developing natural resources i.e. land, water and vegetative growth.

Social Impacts: The artificial glacier projects created a social cohesion among the village people and lessened the quarrels and tensions over the scarce resource.

- Ladakh is essentially a peaceful region where different communities co-exist in spite of different religions, caste, etc. However, traditionally and even today, one main source of dispute arises from use and distribution of water resource which is the most scarce and valuable natural resource. One evident impact of the artificial glaciers on the social life can be perceived in the form of reduced water disputes amongst neighbours and families because of the additional water generated by the artificial glaciers.
- Increased confidence and interest in farming activities thereby resulting in decreased migration of villagers to urban areas for seeking new employment opportunities.

Ice Stupas: The Ice Stupa Artificial Glacier Project was built in the winter season of 2014-15 in Phyang village in Ladakh, as part of a collaborative effort to conserve water and battle climate change. The artificial glacier created resembles with the Stupas, thereby, it was named 'Ice Stupa'. Stupas are the cylindrical shaped domed pillars, a symbol of Buddhist Ladakhi culture which stands evidently throughout the remote landscape of entire western Himalayan region. The brain behind this novel technique of creating ice stupas is Sonam Wangchuk, a local mechanical Engineer and founder of SECMOL (The Students' Educational and Cultural Movement of Ladakh) Alternative School in Leh, Ladakh.

The Ice Stupa Project was conceived by its mentor to try and do away with the site specification problem of creating artificial glaciers. First a prototype was experimented at the lowest altitude near the SECMOL

Ice Stupa Prototype in the month of May -2014

A traditional mud Stupa

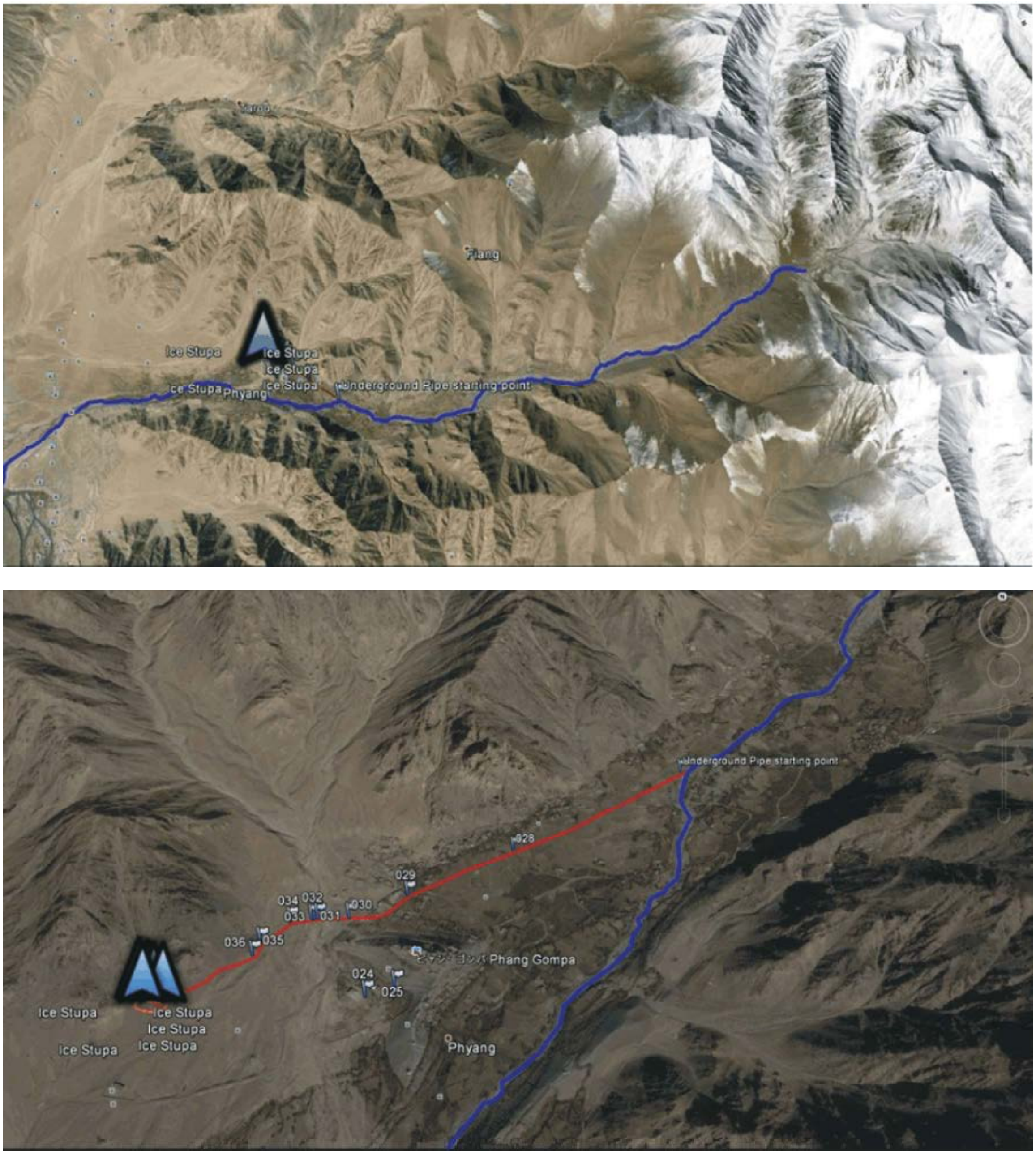
School in the Leh to see its feasibility in year 2013-14. The idea behind artificial glaciers is to freeze and hold the water that keeps flowing and wasting away down the streams and into the rivers throughout the winter. So to hold this water through icing technique in freezing winters and make it to melt in the springtime just when the fields need it most during sowing period. The need to create artificial glaciers in vertical shape in stupa form was to overcome the problems and limiting factors associated with horizontal shaped long stretched artificial glaciers that are site specific, require high altitude locations (3700 – 4000m), constant maintenance and north facing valleys to shade the ice from spring sun.

In order to test the idea of creating artificial glacier in vertical conical shape from the upstream water, a prototype was first experimented in the winter of 2013-2014 at the SECMOL Alternative Institute. The choice of spot was such that it is fully exposed to sunlight and located at the lowest altitude of 3170m (hence warmest) possible in the whole of Leh valley i.e., on the bank of Indus at the SECMOL School campus near Phey Village. This was done to prove that if it works in these conditions, then it can work anywhere in Ladakh. It took about one month to build an Ice Stupa approximately 7m (22 feet) in height, fed by the campus supply pipe which had its headwork roughly 15m above the spot. The experiment was a success as the Ice Stupa lasted until mid May to melt and provide water. Delighted with the prototype, the institute in collaboration with the Phyang Monastery planned for the full scale structure which can turn the Phyang desert to green. In the new model, the artificial glacier is achieved by freezing the stream water vertically in the form of huge ice towers or cones of 30 to 50m height that look very similar to the local sacred mud structures called ‘Stupa’. These ice mountains can be built right next to the village itself where the water is needed and water from upstream diverted to the area where the structure needs to be created. Normally the head difference is easily 100m over a distance of roughly one to three kilometres in the Ladakh topography.

Raising of Finances: With the concept itself proven, the biggest challenge was the cost implication to execute the project. In the past when the people of Ladakh built *Stupas* they relied on ‘*hala*’, a system of donating labour based around the monastery. In this digital age, the team raised the finances online through Crowd Funding worldwide.

The funds to the tune of $1,25,000 (Rs. 75 lakh) were raised on the American crowd funding platform Indiegogo and deposited into the official accounts of Phyang Monastery which are being used in greening the Phyang desert through Ice Stupa Artificial Glacier Project. A total of 330 contributors from 31 countries across the globe raised a total of $125,200 (105% of the goal) at the close of the campaign (23rd December, 2014). Contributions ranged from $5 to $5000 and above. Out of 330 contributors, 10 people donated over $5000 and India accounted for 35% 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.

Design and Structure of Ice Stupa: The whole design and structure of Ice Stupa Project can be divided into three components viz. (i) the headworks and diversion channel (ii) the main site where structure of vertical glacier needs



Pic. 5: GIS Imagery with blue line as natural stream and red line as underground diversion pipe to ice stupa base site

to be created and (iii) the distribution channels. Among these components, about 50% of the project cost has been incurred on the underground laying of pipe almost two to three feet deep so that the running water does not get freeze until it reaches the site for glacier creation. The length of underground diversion pipe is 2.5 kms long with a drop in head (difference in height from inlet and outlet) of 65 metres. As water maintains its level, the water piped in from 65 metre upstream would easily rise close to 60 metre up through vertical pipe from the ground level at the glacier creation site level. The site was water proofed with the locally available clay so that there is minimum seepage when the ice stupa start melting. The base of the site was made dome shape of iron pipes with a tunnel in which men can move inside for carrying operations. This iron bar dome structure is covered with thick polythene as shown in the picture.

Dome shaped iron bar structure

Polythene cover on the dome & tunnel

Sprinkler mounted on the top of pipe which comes out from the centre of the dome makes the water from above to fall in small droplets and the frigid wind freezes the droplets as they hit the ground. To speedup the ice formation process, the structure is covered with thorny twigs of seabuckthorn all around. A cone of ice gets built up slowly but steadily. When the water gets freezed and covered with ice structure initially upto 10 metre height, it is added by another pipe below under the hollow dome shaped structure and water is made to fall from above the previously freezed structure till it gets freezed to top. In this way, pipes from below are added and water is made to fall from higher and higher levels whereby ice structure get mounted higher metre by metre as the thickness of ice grows finally reaching close to the height of source. In this way a huge ice stupa of conical shape with a height of 20 metre and basal radius of 7 metre was created storing roughly about 16 million litres of water.

Day view of Dome shaped structure

Night view with water sprinkler above

The best period for ice formation is the months of December –January when the night temperatures are generally -20 to -30 degrees Centigrade. The ice stupa gets formed till mid March and then starts melting with beginning of April.

Pic. 6: Scintillating Ice Stupa structure at night

Table 4: Characteristic features of the Ice Stupa Artificial Glacier Project

Particulars	Features/Remarks
Name of Village	Phyang (15 kms from Leh district headquarter)
Altitude of Ice Stupa site	3566 metre
Water Source	Glacial stream
Diversion Channel	2.5 km underground HDPE pipes convey water from upstream
Head drop	65 metres between the inlet and outlet of pipe
Ice Stupa Base	Base is plastered with clay to minimise seepage on which dome shaped iron bar structure with an approach tunnel is made and surrounded with thorny bushes.
Equipments/Tools	A raingun sprinkler is mounted on the vertical GI pipe to split water through gravitational force
Dimensions of Ice Stupa	20 metre height and 14 metre basal width conical shape
Water storage capacity	16 million litres
Formation duration	Mid November to end February
Melting period	Starts from beginning April and lasts till Mid June
Cost involvement	The major cost component was on underground laying of pipes (Rs 30 Lacs) and about 3 lacs for operational expenses. The cost per unit of water stored will get reduced as the scale economies will prevail in future course of action due to formation of cascade of ice stupas from the same diversion line.
Funding	Contributions from 31 countries across the globe raised a total of $125,200 (Rs 75 lacs) through American Crowd Funding Platform Indigiego online.
Implementing Agencies	SECMOL Alternative School & Phyang Monastery, Leh
Target Area	Phyang desert of 600 hectares
Future Plan	To build cascade of ice stupas which can irrigate and turn entire Phyang desert into green area.

Pic. 7: Ice Stupa formation in Phyang desert

The objective was to conserve towers of ice as long into the summer as possible so that as it melts, it feeds the fields until the natural glacial melt waters start flowing in May-June. Since these ice cones extend vertically upwards towards the sun, they receive fewer of the sun's rays per the volume of water stored; hence, they will take much longer to melt compared to an artificial glacier of the same volume formed horizontally on a flat surface. The ingenious method stores water without the need for concrete water storage tanks or dams. While it won't stop glaciers from shrinking, it could help people adapt to a warming world in the region.

Potential Impacts: As the Ice Stupa Project is at its infancy stage, in the initial stage, 5000 tree saplings of willow and poplars were planted below the glacial structure on the desert which are supplemented by the melt water. Initially they want to create greenery in the

Pic. 8: Plantation round the serpentine water course below the melting Ice Stupa

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 Rs. 7000. 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 Rs 2.84 crores with discount rate of 10 per cent. As the implementing agency is planning to build a cascade of ice stupa structures (80-90 stupas) about 30 metre tall which can store one billion litres of water, enough to irrigate the entire desert of the Phyang (600 hectares) with plantation potential of 2 million trees.

Apart from the monetary gains from the project, it will improve the environmental and ecological services in the desert area by turning it to green through plantations, 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 entire cold arid desert as of now only nearby glacial stream patches are green and sustain agriculture, rest is all barren desert. As the technology of Ice Stupa formation has no site specificity, it can be built in any area of Ladakh where the natural stream flows.

The Ice Stupa formed last year gained a height of 65 feet and surpassed the Guinness World Record by 11 feet for the tallest man made structure set in China in year 2010. However, the implementers have no plans to register since it was much smaller than their own set target of 100 feet which was not achieved due delay because of the defunct supply of pipes from the supplier which got broken during underground laying and were latter on replaced by the HDPE pipes of high density.

Relevance Of Artificial Glaciers With Climate Change: The creation of artificial glaciers is a high altitude water conservation technique in the wake of climate change. As the glaciers are receding rapidly and winters are getting 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. So the construction of artificial glaciers is a means for harvesting glacial melt water for the irrigational needs of farmers which otherwise goes waste when it is of no use. Natural glaciers are way up in the mountains and melt slowly in summer and thereby reach the villages in June whereas, artificial glaciers start melting in spring right when the first irrigation requirement called '*Thachus*' (in Ladakhi which means 'germinating water') is most needed.

The history of glacier growing goes back to 13th century when the news of Genghis Khan and his marauding Mongol hordes reached what is now the northern Pakistan. The people there came up with an unlikely means of keeping them out by simply growing glaciers across them according to local legends [26]. Whether or not these stories are true, the art of glacier growing also known as ‘glacial 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 for grafting of new glaciers in the region in order to improve the water supplies to villages with limited access. Can artificial glaciers help compensate for the disappearance of naturally forming ones? 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 for improving the art of glacier growing to address the water problems of such regions. The technique of creating artificial glaciers or ice stupas need 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 metre altitude range; temperature as low as -15 to -20 degree Celsius during peak winters; and longer winter periods of four to five months to ensure longer expansion and formation of glaciers.

CONCLUSION

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 of the global population is projected to live in water stressed areas [27]. In general, arid and semi-arid regions are predicted to experience significant temperature increases and reduced precipitation. Under these circumstances, it becomes highly important to capture and store the 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. The need of the hour is to scale up the technologies for mitigation of climate change impacts like that of the artificial glacier technology and solar greenhouse low carbon vegetable production in ecological harsh and fragile environs. It is important to strengthen local knowledge, innovations and practices within social and ecological systems as well as strengthening the functioning of institutions relevant for adaptation. Sound science together with credible, salient, legitimate knowledge is important to support the development and implementation of sound policies. Researchers and developmental agencies need to further improve such adaptive technologies and funding should come forth from the donor agencies for implementing of such technology on wider scale.

REFERENCES

1. Singh, N and Z Ahmad (2005): “Solar Green House Technology for Vegetable Production in High Altitude Cold Arid Regions”, Field Research Laboratory, DRDO, Leh, Ladakh.
2. Dauley, H.S., 1987. Technologies for Integrated Development of Agriculture in Arid Areas, in M. Shafi and M. Raza (ed) Dry Land Agriculture in India (Rawat Publications, Jaipur, India) pp: 71-78.
3. Digest of Statistics, Various Issues (2015-16, 1991-92, 2008-09), Directorate of Economics & Statistics, Planning and Development Department, Jammu and Kashmir Government, Srinagar, J&K.
4. Bisht, I.S., P.S. Mehta and D.C. Bhandari, 2007. Traditional crop diversity and its conservation onfarm for sustainable agricultural production in Kumaon Himalaya of Uttaranchal State: A case study. Genetic Resources and Crop Evolution, 54: 345–357. doi:10.1007/s10722-005-5562-5.
5. Nüsser, M., 1998. Nanga Parbat (NW-Himalaya): Naturräumliche Ressourcenausstattung und humanökologische Gefügemuster der Landnutzung [Nanga Parbat (NW-Himalaya): Natural resources and human-ecological pattern of land use] (Bonner Geographische Abhandlungen, Vol. 97). Bonn: Dümmler.
6. Saxena, K.G., R.K. Maikhuri and K.S. Rao, 2005. Changes in agricultural biodiversity: Implications for sustainable livelihood in the Himalaya. Journal of Mountain Science, 2, 23–31. doi:10.1007/s11629-005-0023-3.
7. Semwal, R.L., S. Nautiyal, K.K. Sen, U. Rana, R.K. Maikhuri, K.S. Rao and K.G. Saxena, 2004. Patterns and ecological implications of agricultural land-use changes: A case study from central Himalaya, India. *Agriculture Ecosystems & Environment, 102*, 81–92. doi:10.1016/S0167-8809(03)00228-7.

8. Dame, J., and M. Nüsser, 2008. Development perspectives in Ladakh, India. Geographische Rundschau: International Edition, 4(4): 20–27 and supplement.
9. Stern, N., 2007. The Economics of Climate Change (The Stern Review), Cambridge University Press, Cambridge, UK, 2007
10. Bates, B.C., Z.W. Kundezewicz, S. Wu and J.P. Palutikof, 2008. Climate Change and Water, Techical Paper. IPCC, Geneva.
11. Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007. Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp: 173-210.
12. Young, G.J. and K. Hewitt, 1990. Hydrology Research in the Upper Indus Basin, Karakoram Himalaya, Pakistan. International Association Hydrological Sciences. IAHS Publication, 190: 139-152.
13. Hasnain, S.I., 2002. Himalayan Glaciers Meltdown: Impact on South Asian Rivers, IAHS Publication No. 274: 1-7.
14. Reiliy, J., 1996. Agriculture in a changing climate. In: Climate change 1995— Impacts, Adaptation and Mitigation of Climate Change: Scientific-Technical Analysis (cd. by R. T. Watson), Cambridge University Press. Cambridge, pp: 427-467.
15. Xu, J., A. Shrestha, R. Vaidya, M. Eriksson and K. Hewitt, 2007. The melting Himalayas: regional challenges and local impacts of climate change on mountain ecosystems and livelihoods. Technical paper. International Centre for Integrated Mountain Development. Kathmandu, Nepal.
16. Miller, G., 2009. Living in the Environment: Principles, Connections and Solutions. Brooks/Cole, Kentucky, USA, pp: 250.
17. Dyurgerov, M.B. and M.F. Meier, 1997. Mass Balance of Mountain and Sub-polar Glaciers: A New Global Assessment for 1961-1990, *Arctic and Alpine Research*, 29(4): 379-391.
18. Dyurgerov, M.B. and M.F. Meier, 2000. Twentieth Century Climate Change: Evidence From Small Glaciers, Proceedings of National Academy of Science, 97(4): 1406-1411.
19. Ageta, Y. and T. Kadota, 1992. Predictions of Changes of Glacier Mass Balance in the Nepal Himalaya and Tibetan Plateau: A Case Study of Air Temperature Increase for Three Glaciers, Annals of Glaciology, 16: 84-94.
20. Yamada, T., T. Shiraiwa, T. Kadota, T. Watanabe, B. Rana, Y. Ageta and H. Fushimi, 1996. Fluctuation of Glaciers from the 1970s to 1989 in the Khambu, Shorong and Langtang Regions, Nepal Himalayas, Bulletin of Glacier Research, 10: 11-19.
21. Fujita, K., M. Nakawo, Y. Fujii and P. Paudyal, 1997. “Changes in Glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994”, Journal of Glaciology, 43: 583-588.
22. Fujita, K., T. Kadota, B. Rana, R.B. Shreshta and Y. Ageta, 2001. Shrinkage of Glacier AX010 in Shorong Region, Nepal Himalayas in 1990s, Bulletin of Glaciological Research, 18: 51-54.
23. Kaul, M.K., 1999. Inventory of Himalayan Glaciers, Geological Survey of India, Special Publication, pp: 34.
24. Ageta, Y., N. Naito, M. Nakawo, K. Fujita, K. Shankar, A.P. Pokhrel and D. Wangda, 2001. Study Project on the Recent Rapid Shrinkage of Summer Accumulation Type Glaciers in Himalayas, 1997-1999”, Bulletin of Glaciological Research, 18: 45-49.
25. Shaheen, F.A., M.H. Wani, S.A. Wani and Chewang Norphel, 2013. Climate change impact in cold-arid desert of North-western Himalaya: community based adaptation in S. Nautiyal *et al* ed. On Knowledge System of Societies for Adaptation and Mitigations of Climate Change, Environmental Science and Engineering, Springer-Verlag Berlin Heidelberg 2013.
26. Douglas Ed, 2008. How to grow a Glacier”, *New Scientist Magazine*, 197 (2461): 1-2, cited on http://www.newscientist.com/article.mg19726412.000-how-to-grow-a-glacier.html?page1-2.
27. Mark Smith, 2009. “Two for the Price of One”, *World Conservation*, The Magazine of the International Union for Conservation of Nature, IUCN, October, 2009, page No. 21.

Annexure-I: Demography, land use and agriculture scenario of the region

S. No.	Particulars	Leh	Kargil	Ladakh Region
(A)	Demographical features			
1.	Geographical Area (sq.km)	82665*	14036	96701
2.	Population (2011 Census)	133487	140802	274289
3.	Literacy rate (%)	65.3	60.8	62.4
4.	BPL population (%)	22.07	31.9	27.3
5.	ST Population (%)	72	87	79.7
(B)	Land use classification			
1.	Total area according to village papers	45167	19459	64626
2.	Area under forests	-	64	64
3.	Land put to non-agricultural uses	2908	1176	4084
4.	Barren and uncultivable land	25163	4578	29741
5.	Permanent pastures & grazing lands	1092	-	1092
6.	Land under miscellaneous tree crops	1147	392	1539
7.	Culturable waste land	4410	3022	7432
8.	Fallow lands	198	134	332
9.	Current fallow	146	229	375
10.	Net area sown	10103	9864	19967
11.	Average holding size	0.75	0.69	0.72
(C)	Area under different crops			
1.	Wheat	2634	1764	4398
2.	Barley	76	3029	3105
3.	Millets	303	571	874
4.	Pulses	306	547	853
5.	Condiments and spices	5	-	5
6.	Fruits and vegetables	439	359	798
7.	Other food crops	4639	895	5534
8.	Total food crops	8402	7165	15567
9.	Oilseeds	86	-	86
10.	Fodder crops	2084	-	2084
11.	Total area sown	10516	10732	21248
12.	Area sown more than once	413	868	1281
13.	Net area sown	10103	9864	19967
14.	Cropping intensity (%)	104	109	106
15.	Total Irrigated area	10516	10732	21248
16.	Net irrigated area	10103	9864	19967
17.	Irrigation intensity (%)	104	109	106
(D)	Livestock			
1.	Total Livestock population	4,75,300	2,88,500	7,64,400
2.	Sheep	1,33,700	1,01,500	2,35,200
3.	Goat	2,62,700	85,600	3,48,300
4.	others	78,900	1,01,400	1,80,900

Source: Statistical Digest, 2015-16, Directorate of Economics and Statistics, J&K.

Annexure- II: Cash flow stream of artificial glacier project

Year	Costs (Rs)	Returns (Rs)	Net Income (Rs)
1	1350000	0	-1350000
2	50000	2095052	2045052
3	50000	2095052	2045052
4	50000	2095052	2045052
5	50000	2095052	2045052
6	50000	2095052	2045052
7	60000	2200000	2140000
8	60000	2200000	2140000
9	60000	2200000	2140000
10	60000	2200000	2140000
11	60000	2200000	2140000
12	70000	2300000	2230000
13	70000	2300000	2230000
14	70000	2300000	2230000
15	70000	2300000	2230000
16	70000	2300000	2230000