Chapter 11
Snow Water Harvesting in the Cold Desert in Ladakh: An Introduction to Artificial Glacier

Chewang Norphel and Padma Tashi

Abstract Living close to nature, Ladakhi's have maintained a harmonious balance with their surrounding. High aridity and low temperature lead to sparse vegetation. Ladakhi farmers have always been dependent on snow and glacier melt water, but the climate change experienced in the last four decades poses a threat for the future. There are different engineering solutions as integral part of water shed management: diversion canal, water reservoir, gravity canal, lift irrigation scheme, and snow harvesting. Only 10–15 % of Ladakhi agriculture benefits from the Indus and Shayok, while the remaining is entirely dependent on snowmelt streams and traditional water management systems of the watershed areas in the cold desert of Ladakh. The system of water distribution during the farming season is strictly followed by the people in their respective villages. Artificial glacier technique is used in the area from 1987. The main stream water is diverted by constructing a long channel made of dry stonewall across the hill slopes to the glacier site. The length, breadth and depth of the channel vary with the slope of the hill as well as an estimated flow of the stream. Dry stone retaining walls and a suitable bed grade to smoothen the follow of water protect the channel from damage. The stone wall is made of locally available stone and a mix of organic manure and soft soil. The technology of the artificial glacier has been in operation in the area for 15 years and is performing successfully.

Keywords Artificial glacier • Cold desert • Ladakh • People's participation • Snow water

11.1 Introduction

Situated on the Western end of the Himalayas, Ladakh has four major mountain ranges: the Great Himalaya, Zansker, Ladakh and Karakarom. Enormously high snow capped peaks and large glaciers outside the polar region dominate the terrain,

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H.K. Nibanupudi, R. Shaw (eds.), *Mountain Hazards and Disaster Risk Reduction*, Disaster Risk Reduction, DOI 10.1007/978-4-431-55242-0_11

where valley heights range from 8,000 to 15,000 ft, while passes of up to 20,000 ft and peaks reaching above 25,000 ft can be seen from all round. This includes Siachen, the world's largest glacier outside of the polar region and such heights determine the temperature of Ladakh. Temperatures go to as low as -30 and -50 °C, with 3 months of sub zero temperatures from December to February. Waterways, waterfalls and lakes freeze, yet during the summer, when the average temperature rises above 20 °C, the sun can be dangerously intense and UV rays can cause deep sunburn. Rainfall is a mere 2 in. and it is the melting snow in summer, which sustains life in this arctic zone.

Ladakh constitutes more than 60 % of Jammu and Kashmir while Leh District encompasses 45,550 km^2, at an altitude of 8,500–15,000 ft. above sea level. The population of the Ladakh region is as low as 132,000; merely two persons per sq. km. The major waterway of Ladakh is the Indus, entering Ladakh from Tibet at Damchok and sprouting from Mount Kailash. The Indus and its tributaries, the Zanskar and the Shingo form the main valleys inhabited by people. Ladakh also has one of the largest and most beautiful natural lakes in the country; Pangong Lake, which is 150 km long, 4 km wide and at a height of 14,000 ft with intensely clear water. Having no outlet the water is highly brackish and the lake basin houses a large wealth of minerals deposited by the melting snow every year. Tso-mo-riri, a pearl shaped lake and Tso-Kar contains also large deposited minerals.

Ladakh, although a remote border area with virtually no surface communication for more than 6 months a year, has always had strong link and contacts with the surrounding regions of Tibet, Himachal, Kashmir, Central Asia and Sinkaing. Pashmina, salt, spices, pearls, metals, carpets, tea and apricots are the main merchandises exchanged through these regional trade links.

11.2 Leh Nutrition Project Overview

Living close to nature, Ladakhi's have maintained a harmonious balance with their surrounding. High aridity and low temperature lead to sparse vegetation. The landscape is desert like with sand dunes and occasional sand storms occur. The agro climate conditions differ with altitude. In the district only 11,000 ha are cultivated agricultural land, which accounts for 0.25 % of the total area. 98 % of the population practice farming. The Himalayan Mountains limit the amount of rainfall in the region to less than 2 in. of rain and 3–4 in. of snow per year.

Ladakhis are therefore dependent on streams from the melting glacier for agriculture. Village communities have sustained a livelihood for the past hundreds of years based on their water harvesting skills. The average land holding of Ladakhi farmers is 1.50 ha. The staple food is barley and wheat. Fruits like apricot and apples are also grown in lower altitude areas. All the different areas are recognized as villages in the official records. One hundred twelve recorded villages in LEH district constitute 95 % of the total land situated in a watershed location. Only 15 % of the cultivated land is dependent on the water of the Indus, Zanskar or Shayok rivers.

Leh Nutrition Project (LNP) is one of the oldest NGO's in Ladakh. It is considered to be an alternative to the Local Government development agencies in many remote pockets of Ladakh, where it has brought quality services in fields of health and education. Rural innovative skills and knowledge for empowerment and sustainable development are a priority. The most remote, neglected and difficult areas of *trans*-Singela and the eastern part of Ladakh, i.e. the stretch south of the river Indus in Leh District, have been the operational areas of LNP for over 25 years. LNP is credited with promoting sustainable development while respecting the traditional Ladakhi way of life. LNP is one of the leading PIA's for implementing the Watershed Development Programme (WDP) in selected remote areas of Leh District, on behalf of the Ladakh Autonomous Hill Development council. Leh Nutrition Project begins projects by carrying out detailed surveys and investigations with active participation of the village communities including children in a Participatory Rural Appraisal (PRA), prioritizing the needs and demands of the village under the Watershed Development Programme. This democratic participatory exercise receives an enthusiastic response by the village community.

The overall consensus of the people is summarized by the following aims:

- Improve the traditional main and distributory water channels of the village by preventing leakages, widening and making them stronger.
- Improve the ancient water reservoirs known as Zings by making them more spacious in depth, height and width, leak proof, and by updating them with water regulating valves and a lock system at their outlet.
- Harness and conserve snow during the winter in high mountains by providing snow barriers and diversions to get additional snow meltwater during the summer.
- Construct new water reservoirs for conserving of winter run-off water for economic utilization during summer.
- Raise artificial glaciers in high mountain belts in watershed areas to supplement water bodies thus an innovation towards regular supply of irrigation water.
- Promote farming skills with new crop varieties, producing early vegetables as health supplements and introducing new technology like trench and poly-green house vegetable cultivation, thus an effective land based income generating avenue for the farming community.

Ladakhi farmers have always been dependent on snow and glacier melt water, but the climate change experienced in the last four decades poses a threat for the future. The older generations witnessed the heavy snowfall of 1–3 ft during the 1940–1950s, when the whole of Ladakh would be covered by snow for 3 months every winter. Villages remained cut off from each other for days. Thick layers of snow hardened after a few days, allowing people to walk over in the early hours of the day to neighboring settlements. Steams used to freeze and children used to skate for months over frozen ice fields. After the snowfall, the swiftness of snow avalanching from the high mountain slopes wreaked havoc on many lives and properties. Unfortunately, today there is rarely snowfall of more then 6 in. in

Ladakh, and the snow that falls melts away within 2–3 days. The streams rarely freeze and children divert water in shady and colder areas to create ice skating rinks. Snow avalanches have become legendary, and glaciers, which have existed for centuries in the High Mountain region, are melting at an alarming speed, strong evidence of global warming. The water flow in the Indus, Zanskar and Shayok has also decreased. If these rapid climatic changes continue, one can expect the oases of village settlements dotted all over the mountain terrain of Ladakh to vanish in years to come. The following parts briefly introduce the six engineering solutions LNP's Watershed Programme has implemented in villages throughout Ladakh.

11.3 Engineering Solutions

11.3.1 Diversion Canal

The wind direction in the mountains is always south to north, with the result that most of the snowfall on the south side is blown up across and deposited on the back side of the mountain due to the low air pressure prevalent there. Thus the north sides usually have thick snow deposits and glacier formations. Therefore north facing villages are always rich in water resources and prone to soil erosion, and a lot of water is wasted during the summer months while south facing valleys experience acute shortage of water. For proper utilization of such otherwise wasted water, a big diversion canal at altitude between 16,000 and 18,000 ft. above sea level have been constructed in the Leh region, for example at Warila, Changla and Nang Phu. Through these Projects 2–20 cusecs (cubic feet per second) of water have been diverted from the north to the south side benefiting more then 400 families. As a result farmers have been able to bring more land under cultivation, and grow more trees and fodder. Hundreds of acres of cultivable land is available in and around the village of south facing watershed, unused for want of irrigation facilities.

11.3.2 Water Reservoir

Agriculture operations in Ladakh are time bonds, as in any other part of the world. Agriculture is completely dependent on timely availability of irrigation water, which is further dependent on availability of snow deposits during the past winter and the rise in the atmosphere temperature, in the spring. Weather conditions differ from year to year, influencing melting of glacier ice and snow in the upper regions, ultimately affecting the sowing time of the crops down in the villages. Sometimes the snow starts melting before the sowing time, resulting in wastage of all the run-off water and sometimes temperatures in the spring season remain so low that no melting occurs until the sowing season is over. To over come such erratic

Fig. 11.1 Water reservoir [Zing] in Ladakh

conditions, a series of reservoirs are constructed across the village, so that any excess water, which would otherwise be wasted, can be stored for economic utilization when needed. Such facilities not only help in economical use of the available water but also help in avoiding conflicts among the farmers which otherwise arise due to shortages of water. Locally called the "Zings," the reservoirs not only help in conservation of the available water for irrigation purposes but also help in recharging the ground water, thus natural springs down in the villages below see increased water discharge (Fig. 11.1).

Traditionally, the village community nominates a few people to regulate the irrigation water for a season, turn by turn, called "Churpons." The numbers of churpons vary depending of village size. These churpons are fully authorized by the village community of the respective villages to regulate and distribute impartially, through direct gravitational channels or through reservoirs depending on availability of irrigation water in that particular season.

The size of the Zings varies depending on the area under its command and feeding water availability. The standard capacity of a "Zing" is 112,000,000–196,000,000 L of water. To improve the capacity of existing zings, LNP's main goals are to strengthen them and to provide them with sluice valves for easy operation by villagers. LNP has taken up several projects and completed them successfully. LNP has also provided villagers with a mechanical locking system to protect from water stealing, which otherwise occurs during acute shortages. A few such projects in hand are still incomplete due to lack of funds.

11.3.3 Gravity Canals

Settlement is found wherever a little irrigation water is found available throughout the district. Since, the manpower and other resources were very limited coupled with very poor tools and implements, even then the old settlers tried to the best of their ability to utilize the available land and water resources to the maximum. Yet plenty of scope is left to bring more and more area under cultivation by tapping the available water resources, by bisecting hard rocks surfaces, which is of course difficult but not impossible in this scientific age with advanced tools, implements, machines and technology. The human population in Ladakh has increased, as in any other part of the country, but the agricultural land has not increased correspondingly, rather it has shrunk due to the construction of road and buildings. The present network of the Government public distribution system has negatively impacted agricultural production and is leading towards a non-sustainable future. Thus, it is imperative to bring more and more land under plough, which is the only way for a sustainable future.

We have taken up a few such projects where irrigation water has been made available for hundreds of acres of land by way of existing gravitational canals, cutting through difficult rock surface and hard terrain. Dha canal, Skurbuchan canal, Tar canal and Skuktsey Thang canal in Khaltse Block are some examples. These canals have been constructed purely in the traditional way, using locally available materials and completely avoiding the use of cements. It is worth noting that they are functioning very effectively. Replication of such projects across the district can definitely increase the amount of agricultural land to a substantial level. Exploration of such potential sites in the district is the need of the day.

11.3.4 Lift Irrigation Scheme

River Indus the Sindhu is the main drainage system, with its tributaries of Shayok, Nubra, Zanskar, Suru and Drass rivers. All of these flow through deep gorges accounting for only 11 % of the cultivated land. Large tracts of cultivatable land on either side of these rivers lie unused for want of irrigation facilities which could not be developed due to difficult geographical terrain. How unfortunate it is that though land and water are available in plenty, these areas can not be utilized for lack of infrastructure such as energy or a feeding canal. For such potential sites lift irrigation is the most ideal arrangement, yet electricity remains a constraint. One can hope that the new 44 MW Alchi hydro power project, expected to come online by the year 2010, will provide power for agricultural purposes, as the electricity generated will be much cheaper than it is currently. Similar hydro projects expected in the future may bring a very positive revaluation in the agricultural field of this arid zone.

11.3.5 Snow Harvesting

Snowfall received on the hillside during winter months is blown across the hill summits and passes, finally deposited on the north facing pockets due to low air pressure there. Providing barricades or walls across the wind direction helps in retaining the snow on the south facing valleys, which serve as a good source of water during the following summer season. It has been observed that construction of a 5 ft. high wall results in deposition of snow in its pockets side to a length of 12 ft. Such barricades have been constructed at many suitable sites and have been found effective. The work is tough, as it has to be accomplished at high altitude, where out put is less due to harsh conditions, but once constructed it lasts for years. Sufficient financial support is needed to take such snow conservation measures.

11.4 Artificial Glaciers

The five previously mentioned technologies are integral part of watershed management in Ladakh. They use the present water and better collect or distribute it. Artificial glacier technology works in conjunction with the five technologies mentioned prior, and is a temporal method for storing water over the long term to counteract the disparity between the agricultural season and water availability.

The technology of the artificial glacier has been operational in the area for over 20 years and is performing successfully (Fig. 11.2). Farmers, in particular, are experiencing positive results from the technology. Hundreds of snow and glacier-melt streams contribute to form rivers, like the Indus, the Zanskar, and the Shayok, which make their way into the ocean, making a small contribution towards agriculture in Ladakh. Only 10–15 % of Ladakhi agriculture benefits from the Indus and Shayok, while the remaining is entirely dependent on snowmelt streams and traditional water management systems of the watershed areas in the cold desert of Ladakh. The system of water distribution during the farming season is strictly followed by the people in their respective villages and is recorded in Rewaj-e-Apashi, the official records of the revenue department. A strict implementation of the system is ensured through a group of Churpon (Mir-Abs), nominated by the farmers by turn each year and these Churpons have the power to penalize those who violate the system. There has been little opportunity for extension of land holdings, as there is little likelihood of sharing the limited water in order to bring new areas under cultivation.

The agriculture season commences in April and May while the process of snow and glacier melting at high altitude begins around the end of June. This delays the sowing of crops, affecting crop productivity. Spring is the most crucial season for farmers, yet little water comes down through streams during spring, as the temperatures do not allow the snow and glacier-melting process. Farmers have to manage the available flow of water as per the established tradition. The traditional ponds,

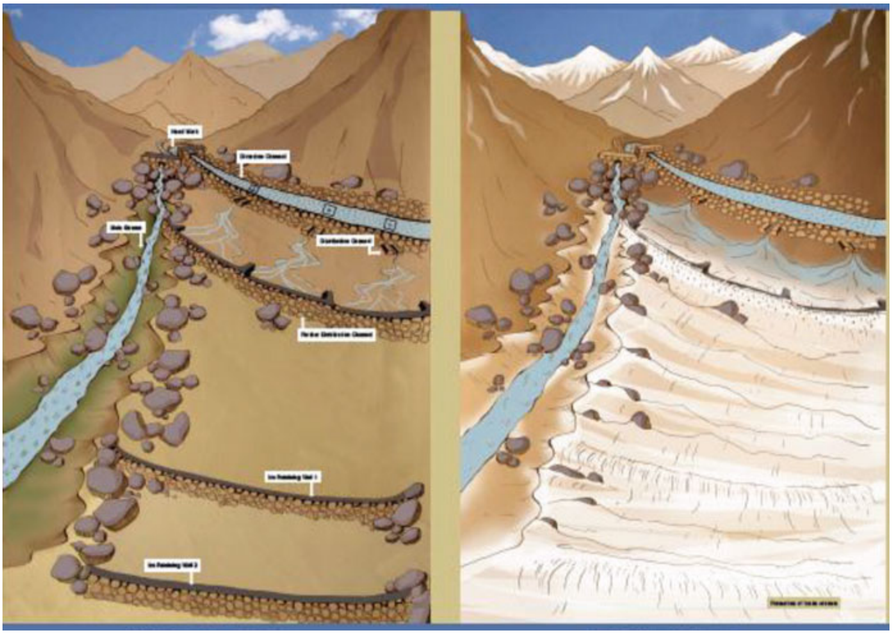

Fig. 11.2 Schematic diagram of artificial glacier

reservoirs and khul existing in many villages are in terrible condition, and cannot store the melting water for a long time. A detailed study was carried out by scientists and engineers to find ways of making the reservoir and ponds more spacious, efficient, and strong. The khul and distributaries were also repaired to improve the efficiency, however, the main problem of making water available to farmer during spring season still persists. The need was therefore felt to develop a technique that would ensure water availability to farmers during the sowing period (April–May).

The innovative technology of artificial glacier formation was implemented with the following objectives:

- Ensure availability of water to farmers during early spring season for cultivation.
- Enhance crop productivity by making water available in adequate quantity and in time.
- Bring wastelands and uncultivated land under economic production.
- Improve the cropping pattern of the farmers.
- Prevent wastage of precious water.
- Mobilize farmer's participation in the management of artificial glacier formation and components of irrigation system.

Artificial glacier techniques were originally experimentally implemented at Phoktse Pho, in 1987. The technology spread to other villages after its initial success. At present the technology is in operation in some villages of the district. The technology for artificial glacier formation involves the following components:

- Diversion Channel/Khul.
- Artificial glacier structure/creation of water bodies.
- Construction of water reservoir.

The main stream water is diverted by constructing a long channel made of dry stonewall across the hill slopes to the glacier site. The length, breadth and depth of the channel vary with the slope of the hill as well as an estimated flow of the stream. Dry stone retaining walls and a suitable bed grade to smoothen the follow of water protect the channel from damage. The stone wall is made of locally available stone and a mix of organic manure and soft soil. The organic manure and soil help to establish the stone wall by mixing in shrubs (plants of which the seed is naturally mixed in the materials), which strengthen the wall. No other materials are used thereby minimizing the cost of construction and danger of getting it washed away, as normally no torrential rain is experienced (Figs. 11.3 and 11.4).

The process of artificial glacier formation is explained hereunder:

1. Collection of data on flow from the main stream to locate where water remains throughout winter.
2. Selection of sites depend on the following:
   - Be on the north side of the mountain and under the shade minimizing the effect of direct sunlight.
   - Not located on a steep slope, but preferably in an unobstructed area with a 20–30° slope.
   - Be at a lower altitude to facilitate the process of early melting, preferably 13,000–14,000 ft.
   - Be near to village so as to make ice melt water available within shortest distances to the cultivated land and minimize the transit loss.
3. Construction of a diversion channel across the hill slope as previously described.
4. Construction of a snow barrier bund/ice retaining bund, consisting of dry stone masonry in crate wire on the lower side of diversion channel at the glacier formation site. Length of the proposed glacier and the numbers of barrier bund depend upon the slope at the site. The greater the slope, the less length between bunds and greater number of bund, with less bund interval, and the vice versa.
5. Releasing the flowing water at glacier site through a number of outlets to facilitate the slow flow of water and allow time for conversion into ice. These operations are completed during May, and continue through till October (as this is the only working season available in a year), as follow:
   - Construction work of structure is completed between May and October
   - Water collection at glacier site begins mid November (at a slow pace)
   - Freezing of water begins at 0 °C
   - Stabilization of ice occurs within 24 h and is converted into an ice mass

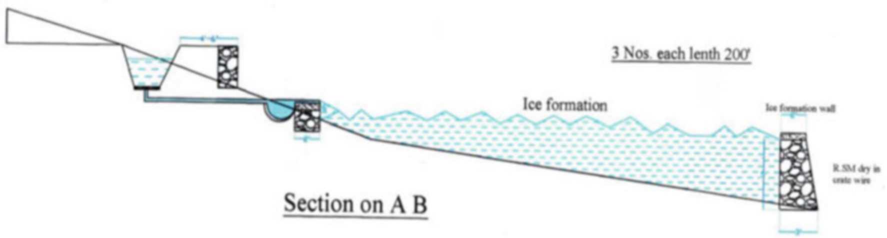

Fig. 11.3 Schematic section of artificial glacier

Fig. 11.4 Photos of artificial glacier

– The glacier remains in place until the end of March, when the temperature rises and thus the melting process begins
– During periods of cloudy weather when the snow melting is slowed or has stopped, the water in the reservoir can be used for irrigation purposes
– Artificial glaciers begin melting earlier than natural glaciers, as the former is located at a lower altitude and exposed to the rising temperature earlier
– Artificial glaciers are complementary to natural glaciers. Though the melting of the natural glaciers depends on glacier size and temperature, by the time the artificial glacier melts completely, the process of high altitude snow melting will have begun

– Melt water from the glacier is stored in the reservoir ponds located at different sites in the village
– Water distribution is regulated by the volunteer appointed by the community through an existing network of khuls and channels
– The active life of the artificial glacier is about 4 months (Mid November to Mid March), however it depends upon the length of the winter and prevailing temperature
– During periods of cloudy weather when the snow melting is slowed or has stopped, the water in the reservoir can be used for irrigation purposes

Concluding Remarks

As previously mentioned, the design of the artificial glacier is dependent on the suitability of the site. Availability of sites in the shade during winter is the primary criteria. It prevents direct exposure of the glacier to sunlight as well as facilitating the process of glacier formation.

1. If the section of the stream is very wide with a mild slope, then the dry stone masonry bunds are constructed in a series parallel to each other. The number and dimension of ice retaining bunds depends on the flow of water available in the main stream during the peak of winter. In November, when winter begins, some locally available wild grass is put on the base of the dry bund to plug any holes. It helps to freeze the water faster.
2. If the section of the 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 of 1:30 ft. When it reaches the glacier site the bed grade should be gradually reduced to a slope of 1:50 ft, allowing it to flow through small outlets. The small quantity of water freezes almost instantly when flowing through these small outlets. Dry stone masonry in crate wire needs to be constructed parallel to the channel in series at a distance of 30–100 ft, according to the nature of slope of the terrain. The steeper the terrain, the smaller the distance and slope between the bunds.

The technology of the artificial glacier has been in operation in the area for 15 years and is performing successfully. Farmers, in particular, are experiencing positive results from the technology success.

1. Water of the artificial glacier melts earlier than that of the natural glacier.
2. Availability of water facilitates early crop cultivation process, i.e. spring cultivation would otherwise begin 20–30 days later, affecting the crop yield. Unused water in the winter that would otherwise be wasted, can now be utilized economically for agricultural purpose. In this region only one crop can be taken and after that the water goes to waste.
3. Availability of water at this critical time helps to increase production of food crops, fodder, trees such as the willow and poplar, and fruit crops.

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4. Water lost to seepage in the system helps to increase and recharge groundwater in the area, and the flow of nearby springs in the village increases considerably.
5. Artificial glaciers can be used despite low snowfall, as water is frozen at lower altitude and converted to ice in the vicinity of village. Location of the artificial glacier nearer to the villages saves villagers time in clearing blockages, and water reaches the fields sooner, reducing wastage.

Due to the terrain of the region (undulation and big boulders), it is hard to calculate the volume of ice. Therefore, the best way of calculating the volume is to measure the flow of the water once a month, giving the exact volume of water, harvested through the artificial glacier. For example, a particular Nahlla (Canal), average flow is 1 cusec, which has been diverted to form ice for a period of 4 months normally i.e. middle of November to middle of March i.e. $1 \times 60 \times 60 \times 24 \times 30 \times 4 = 10{,}368{,}000$ cubic feet of ice. On the surface you will not find this much of volume, because same percentage of water, say 20 % will be absorbed by the soil during the ice formation process. This absorbed water helps the recharging of ground water. The evaporation loss is considered negligible because of the severe cold. Out of 1,036,800 ft, 8,294,400 ft of water can be available for irrigation. This much water is enough to irrigate 380 acres of land once. One pre-sowing irrigation is required to bring the fields to optimum level, under Ladakh conditions. Artificial glacier technology is fairly simple to replicate and requires the following criteria:

1. Temperature lows of −15 to −20 C during winter
2. Winter period of 4–5 months minimum
3. Glacier melt water dependent villages

Locations with similar geo-climactic regions to Ladakh are likely to be able to use the technology, for example: countries like Kazakhstan, Kygyzstan, China (Tibet), Nepal, and within India, parts of Himachal Pradesh, such as Spiti.