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TRADITIONAL WATER MANAGEMENT OF SUBSISTENCE AGRICULTURE SYSTEM IN COLD ARID LADAKH: A REVIEW

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Abstract— Ladakh is an extremely harsh and driest inhabited high-altitude region with subsistence economy based on an agro- pastoral system, supporting 80 per cent of its population. Glacio-fluvial processes aided by freeze-thaw weathering have designed the high-altitude landscape of Ladakh for livelihood options. In spite of harsh climatic conditions, people have managed to develop a remarkably productive subsistence agricultural system which relies exclusively on glacier melt water from glaciers, snowfields, and permafrost is the most important source well adapted to this unique and extreme environment. Simultaneously, Ladakhi social structure has developed a community-based approach of utilizing natural resources such as glacier-melt water according to the traditional distribution system, importance of which at present, increases with receding glaciers, impacting livelihood of deep-valley based farming systems. Adoption of location specific scientific interventions is the only ways to take bring back the Ladakh farming from subsistence to a sustainable and utilizing improved micro-irrigation technologies involving policy makers. This chapter deals with the efficient ways to utilize the irrigation resources in a judicious manner and its scenario as to how systems have regulated and facilitated both the agriculture process and the social, cultural and community life organized around farming and related occupations is discussed.

Index Terms— Cold arid regions, Ladakh India, subsistence agriculture, water management.

1 Introduction

AGRICULTURE sector is considered as the backbone of Indian economy particularly of hilly region like Ladakh which is mainly dependent upon the available wealth of natural resources. It is the high-altitude Trans-Himalayan region with special agro-climatic features. The ecosystem is highly fragile due to its arctic and desertic inhabited places. In India cold arid region lies in north western Himalayas of Jammu and Kashmir and Himachal Pradesh. About 87.4% of total cold arid in India is in Ladakh region (45,110 km^2 area) (1). The low temperature of the area during most part of the year accompanied with scanty rainfall, low humidity, high evaporation, transpiration and soil erosion hazards pose constraints for agricultural production with scarce water resources, high PET losses, harsh dry winds and totality of harsh and tough climate conditions, hindering the agricultural activities (2). It lies between 32º 15′ - 36º N and 75º 15′ - 80º 15′ E, and is a high altitude cold arid region of India (3). Ladakh remains cut off for almost seven months i.e., from October – May from rest of the world by surface transportation due to harsh winter, and heavy snowfall. The climate change impacts on agriculture and other prime sectors of Ladakh region is more vulnerable in view of excessive pressure on natural resources; hence it becomes imperative to utilize the available natural resources in a manageable way and advancement in agriculture for sustaining agricultural production and productivity. Scarce water resources including precipitation (less than 150 mm) are quite inadequate to meet the average requirements of the crop plants. The only source of available irrigation water is the glaciers placed on high altitudes which melt and flow during summer season. The availability of this water is not easily predictable because it depends on the amount of snowfall in preceding winter receipts. Glacier-melt water is the prime source of irrigation for sustaining agricultural production under efficient utilization managerial pattern. Under this situation, supplementary irrigation becomes essential to raise the crop and the form of glacierized melting water is only major source of irrigation. In order to deal with recurrent water scarcity, different types of ice reservoirs, commonly called “artificial glaciers,” have been introduced in Ladakh and promoted as appropriate adaptive strategies to cope with changes in the cryosphere. It increases meltwater availability during the critical period of water scarcity in spring. The people are managing the unpredictable resources by the local institution (4), which is called community irrigation. In this method water is supplied to farmers for irrigation in a rotational manner. Besides this, to address the issue of water management farmers are also following micro irrigation which becomes prevalent in cold arid region. Micro-irrigation resulted in significant increase in yield, quality, and fertilizer utilize efficiency in vegetables.

With sparse vegetation there is little moisture in the atmosphere. Most of the land is covered by mountainous desert, rocks, sand and dust. Only small parts (valleys) are suitable for cultivation and animal husbandry. A system of terraces and irrigation canals, patches of land are made arable wherever possible.

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The major constraints faced by the inhabitants of cold arid region of Ladakh are:

1. Low and erratic rainfall
2. Sandy terrain with high permeability
3. High evaporative demand
4. Salinity of groundwater
5. Target oriented development of water resources
6. Poor socio-economic condition of local population
7. Lack of education
8. Poor market

2 HISTORY

Irrigation technology was introduced in the tenth century from neighbouring regions when the first canals were constructed (5). Water, flowing close to the village, is shortly diverted to irrigate fields and managed according to a traditional communal system that has been defined as a "fine-tuned mechanism for distributing water equitably and efficiently" (6). Moreover, due to the dimension of the source, meltwater could be considered a renewable resource, flow limited, whose use must be optimized, but the stock is seemingly far from exhaustion.

As the rainfall during summer is quite scanty and inadequate to support to higher plant growth, it is inevitable to develop suitable water conservational and utilization method. Moisture conservation in soils of Ladakh can be achieved by compost mulch which prevent evaporation losses. Drip irrigation, pitcher irrigation or sprinkle irrigation should be used where it is possible. It would be much better if all the fore said methods of irrigation need to be experimented to assess their usefulness in cold arid region (2). Glacier melt is the major source of water used both for irrigation and household consumption.

The area under cultivation is increasing gradually with changes in cropping pattern as per the market demand. On the other hand, correspondingly, the irrigated area under crops in Leh district seemed at par. So, it is apparent that Ladakh rely on glaciated water and river resources with change in cropping pattern over the period of times.

3 SOILS AND QUALITY OF IRRIGATION WATER

The soils are sandy to loamy in nature, deficient in organic matter and low in phosphorus and potash. They are mixed with boulders and gravels. It is shallow, weak and friable. Being sandy it is vulnerable to all types of erosion. Soils developed on river terraces are highly porous and coarse grained in nature. Fertility of the soil varies from place to place with very short crop growing season. Irrigation water is the most important resource to a farmer in Ladakh (Trans-Himalayan cold arid high-altitude region of India). In many areas the stream water is passed through different villages, e.g., Phyang (upstream) and Phey village share the same stream water.

The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil. Irrigation water of Indus and Nubra valleys falls under C2S1 and C1S1 class which is of good quality (Table1) (7). There is no hazard of salinity, sodium, and bicarbonate levels and Zn & Mn concentration in irrigation water of Ladakh region and therefore can be used safely in agriculture for growing crops (7). The quality of ground water is fresh and potable. The Electric Conductance ranges between 37 μ mho/cm (Khardung Chik-chik) to 760 μ mho/cm (Panamic Yogma). The exceptional value of 1073 μ mho/cm was recorded in water of Panamic Lake. The pH ranged between 7.1 (Murgi) to 8.8 (Skampuk-TW). The pH value of lake water of Panamic Yogma village was 9.2 (8).

TABLE 1:
IRRIGATION WATER QUALITY OF INDUS AND NUBRA VALLEYS

Parameters	Units	Indus Valley	Nubra Valley
pH	-	7.93	7.90
EC	μScm^{-1}	265.9	156.53
TDS	ppm	127.3	74.39
Na	mel^{-1}	0.73	0.59
Ca + Mg	mel^{-1}	2.73	1.87
CO_3+HCO_3	mel^{-1}	2.96	2.21
Cl	mel^{-1}	1.18	1.73
K	mel^{-1}	0.054	0.066
Zn	ppm	0.0084	0.0065
Mn	ppm	0.0074	0.0056

Farmers irrigate their crops 5-8 times, considering glacier water more productive compared to dug-well or tubewell. Natural water passes through various soils, weathered materials and natural grasslands enriching its quality at high altitudes after melting, and this benefits the crops. Tube well/ borewell water makes the upper soil layer harder while glacier-melt brings soluble salts with various ingredients which make the soil fertile and crops respond for better productivity. The nutrients being water soluble are easily available to the plants (9).

4 REGIONAL CHARACTERISTICS AND SCOPE OF IRRIGATION WATER

Hydrologically, Leh is underlain by consolidated formation in maximum part. Ground water in these formations occur in fissures and fractures developed due to repeated tectonic activity. Hydrogeological investigation during 2004-05, eighteen springs were inventoried and it revealed that the yields of these springs range from 1.5 lps (Yulkum) to 290 lps (Boudang). These springs normally are being used for domestic purpose but they also serve as sources of irrigation (8). Under these circumstances, most of the farmers depend upon the natural resources especially glacierized melted water. But every farmer gets its share of irrigation water and therefore the total cultivated area of 10196 hectares is irrigated with the available sources like through canal irrigation, glacier melted water, river water etc.

5 ISSUES AND PROBLEMS

Springs are getting drying and glaciers receding due to global climatic changes and causing erratic flows, resulting dramatic downfall in crop productivity (Saboo area surveyed). Springs under such situation are major traditional sources of water supply for villages. To mitigate the water supply crisis, hand pumps and tube wells are being explored but restricted to few areas. As a result of these, villages become largely depend on glacial runoff for water for their agriculture and livestock uses.

5.1 Temperature rising in Himalayas

India Meteorology Department data showed that in past 35 years, minimum temperatures was ris-ing by nearly 1 degree Celsius in Ladakh during the winter months and 0.5 degrees Celsius during the summer. The mean minimum temperature during November, December and January (the peak winter months) is -7.80C, -120C and -14.20C, respectively and showed the decline trend in pre-cipitation amount from November to March dur-ing the period from 1973 to 2008. Being on the leeward side of the trans-Himalayan range, Ladakh is cut off from the south-west monsoon. The desert district receives just about 102 mm of precipitation annually. Not only is the total amount of precipitation showing a declining trend (10).

5.2 Harvesting the snow-melted water and methods of irrigation

Glaciers in Ladakh region forms a major source of utilization for sustaining life is brought to the field by making Kuhls (Water Channels). Water Harvesting from snow melting is practiced by constructing water ponds on depression-side of the entry of the village from glacier side and water is collected in Zings (ponds) from melting snow and locally known pang (Spang) i.e. Trisetum species grass is grown around the ponds to control the seepage and side losses in water tanks and irrigation kuhls. Farmers either doing irrigation by flooding by snow-melted water and/ or diverting river water. Drip irrigation as latest technology is also under use. Deposition of fresh silt with unweather minerals (especially lime) forms glacier source of fresh salts and the glacier melted water is often below 2°C which protects the crop from different kinds of diseases.

For checking the field condition, farmers regulate optimum irrigation by inserting a belcha (spade) in the soil. Complete insertion of the front portion of belcha or throwing of mud in the air and its consequent splitting into pieces indicate the soil moisture level at field capacity, where 100 per cent moisture is available to the crops (11).

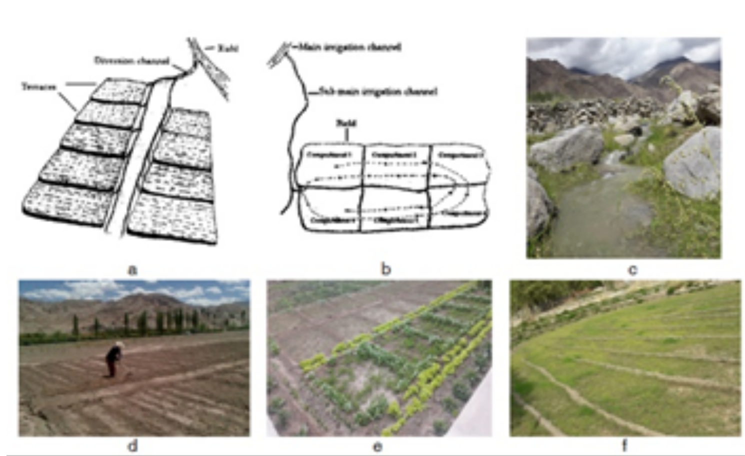
5.3 Glacier water management

Agriculture with harvesting glacier water in the lap of Himalaya has come-up as a small-scale farming system, well adapted to this unique and extreme environment (12). Distribution of water to the households is monitored by a supervisor known as chhurpon (chhu= water; spon= Lord), appointed in a community meeting and arrange yura-phunske where all the villagers used to clean water channels, streams going towards agricultural field. He is expected to have knowledge of water flow-chart, priorities, and field conditions, crop requirements and order of distribution to households and decide the ponds to preserve the water during scarcity period. It is dependent and determined upon the precipitation received and glacier situation, especially during onset of sowing season. After harvesting, fields are irrigated for freezing the soil during October and this supports during spring season when thawing occurs. In Ladakh, farmers have small land holdings of which some of the portions are utilized for vegetable farming at small scale and fields are divided into smaller sub-plots for irrigation, otherwise land being sandy, water percolates immediately through one large plot. Simultaneously, Dzo-plough in Ladakh cultivates the fields without disturbing and bringing to the top the bottom soil and humus on top soil also does not turned into and perform as mulch for optimum use (5).

In the region, crop cultivation without irrigation is not possible because precipitation takes place in the form of snowfall. People take advantage of glacial water and perform collective operations for effective distribution and ensured supply of this scarce source. The management of water in a particular field is regulated by apportioning into different compartments because of the season. The mouth of first compartment is closed to regulate the flow of water towards the second compartment. The schematic water management have been shown in Fig 1.

5.4 Irrigation water management in Leh

Leh receives scanty rainfall and fed by numerous rivulets that stream down glaciers in this region. In irrigation activities Indus river canals and artificial glacier melts play an important role. However, efforts are being made for bringing more barren land under cultivation by constructing irrigation canals on the Indus, Shayok and other tributaries. Community approach in distribution of irrigation water is very unique and honest one. Every household gets glacier recharge water as irrigation at fixed schedule by informing each other timely. Total irrigated area in the regions is 10424 hectares, most of which were covered by Canals and Khuls.



a & b-Sketches of irrigation channel preparation, c-use of glacier water; d-field irrigation channels at CAZRI, Stakna; e-farmer's vegetable garden; f-strips for staple food crops on large area. Source: a&b-Verma, 1998

Fig.1. Irrigations water channels

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On the contrary, the alarming situations of global warming in cold arid region likely to reduce the amount of snowfall, reducing the water flow in snow-fed rivers during the summer months and WWF (2010) which creates water security. To address this water scarcity issue micro irrigation plays a major role where precise placement of water and fertilizer can be done in the root zone by evading the losses and ultimately it increases the water saving and utilisation efficiency in cold arid zone. Traditionally Ladakhi farmers have catalogued the irrigation management in their local pattern has been depicted in Fig.2 (13). There are various forms of Ladakhi vernacular irrigation pattern during irrigating the crop fields. This method of traditionally developed watering of the plants maintains the equal flow, checks the nutrient loss from field to field and from one bed to another.

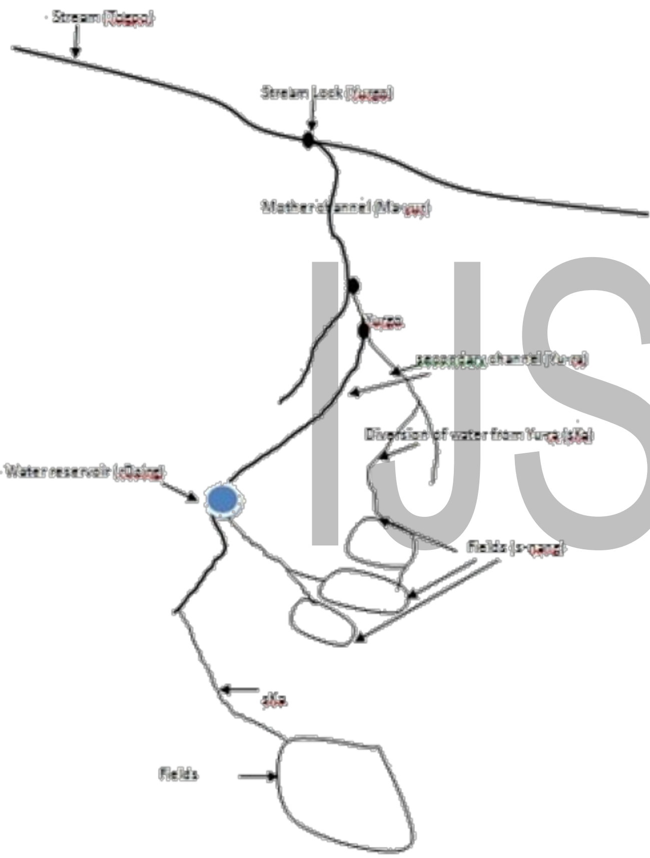

Fig. 2. Schematic diagram of stream flow –monitored by Chhurpon (water Manager)

In this region, irrigation schedules have been standardized for different crops. These crops and their varieties are well acclimatized to the harsh, dry and cold climate are listed in the following Table 2 as per their crop stages such as germination (tol-chhu), growing (sak-chhu), flowering (non-chhu), seed setting (gep-chhu) and crop ready for harvest (do-chhu) (11). Here chhu is known as water. Although crops are irrigated as the soils are sandy loams and require more irrigations but these stages are kept in mind.

In Ladakh region, the possibility of exploring tubewells, canals and even lift irrigation is limited due to its altitude and barren ecosystem and are confined to the low laying areas near Indus plains. Therefore, the most common source of irrigation remains the glacierized based irrigation water. The progress of the sources of irrigation so far explored has been mentioned in Table 3 (14). It is clear from the tables that there has not been a much progress on either wells/ tubewells or tanks or others but the cultivated areas have been shown as under irrigated command areas. Most of the areas are irrigated through canals where glacier melt water is utilized. There is no change in cultivated area since last 20 years (Fig.3) (14).

TABLE-2:
TRADITIONAL GERMPLASMS OF AGRICULTURAL CROPS IN LADAKH REGION

Crops	Var. of crops	Tanslit	Meaning
Barley	Ne-nak (Lad, nak-nas)	-	Black-Barley
	Yang-ma	Gyong-ma	Early ripening
	Yang-Kar	Eyeing-dkar	White wealth
	Sermo	-	Yellow mother
	Tug-zur	Drug-zur	Six cornered
Wheat	To-Chen	Gro-chen	Big wheat
	To-chen	Gro-chund	Small wheat
Peas	Sren-mar	Sran-mar	-
Alfalfa	Buck-suk	-	-
Lucerne	(Lad-lol)	-	-
Mustard	Nyus-Kara	Yungs-dkar	-
Buck wheat	Ta-wo	Bro-wo	-

Number of irrigations has direct impact on yield parameters and yield per kanal (500 sqm). In mountain regions, irrigation has been practiced traditionally as an art and scheduling of irrigation has been designed (Table 4) (4). Agriculture production is entirely based on irrigation. Glaciers are the major source of irrigation water and the rivers that flow in the region remain underutilized for agricultural purposes, particularly in remotely located valley villages. Villages of valley based established at varied altitudes have capacity-based irrigation numbers to irrigate their crops due to the recharge capacity of glaciers (Table 5). While others are Indus based villages where crops are irrigated using canal/ river water. In such circumstances, number of irrigations and yield of crops vary significantly.

Water for irrigation comes from glaciers through canals diverted into smaller arms that reach the fields. Water quantity and number of irrigation times during the growing season depend on different factors: kind of crop, soil, field topography and location, average evapotranspiration. At the beginning of the farming season, around April-May, local farmers hope for long warm sunny days (to melt ice), instead of wishing for cloudy weather like the agriculturists who live in regions watered by monsoon rain: "When glacier forms in phu [high altitude areas], ocean is formed in the lower parts; thundering cloud has no rain, the gossip girl has no wedding" (5).

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Meltwater from glaciers, exploited through an artificial channel system, plays a crucial role for irrigation (15). Glaciers are remote and out of the farmers' control: their dependence on global climatic conditions makes the farming system dependent on exogenous factors. Meltwater flow for irrigation and organic matter and nutrients in soil are the main limiting factors of the traditional farming activity.

TABLE-3:
SOURCES OF IRRIGATION (AREA IN HECTARES)

Year	Net Area Irrigated				Gross Area Irrigated			
	Canals	Wells & Tube Wells	Tanks/ others	Total	Canals	Wells & Tube Wells	Tanks	Total
1991-92	10309	0	0	10309	10623	0	0	10623
1992-93	10196	0	0	10196	10257	0	0	10257
1993-94	9985	0	0	9985	10360	0	0	10360
1994-95	9942	0	0	9942	10430	0	0	10430
1995-96	10414	0	0	10414	10789	0	0	10789
1996-97	9920	0	0	9920	10475	0	0	10475
1997-98	9940	0	0	9940	11000	0	0	11000
1998-99	9012	0	0	9012	9224	0	0	9224
1999-2000	8476	0	0	8476	9162	0	0	9162
2000-01	8476	0	0	8476	10493	0	0	10493
2001-02	8496	0	0	8496	10523	0	0	10523
2002-03	8460	0	0	8460	10478	0	0	10478
2003-04	8416	0	0	8416	10424	0	0	10424
2004-05	10117	0	0	10117	10428	0	0	10428
2005-06	10189	0	0	10189	10585	0	0	10585
2006-07	10554	0	0	10554	10585	0	0	10585
2007-08	10193	0	0	10193	10599	0	0	10599
2009-10	10196	0	0	10196	10608	0	0	10608
2010-11	10197	-	-	10197	11692	-	-	11692
2011-12	9824	-	-	9824	10319	-	-	10319
2012-13	6735	0	0	6735	7367	0	0	7367
2013-14	7963	0	0	7963	8595	0	0	8595
2014-15	9684	0	298*	9982	9926	0	0	10614
2015-16	9628	0	296*	9924	9960	0	0	10542
2016-17	9667	0	296*	9963	9958	0	0	10540

5.5 EFFORTS FOR ARTIFICIAL GLACIER

The melting water from the glaciers has been the only source of irrigation for 80 percent of the villagers in Ladakh. But It has been observed a decreased and untimely snowfall. This is due to changing climate. Winters are getting shorter and with less precipitation and whatever little snowfall is received melts away quickly much before it can be put to use in the barley fields in the sowing season. Along with this only one crop can be cultivated due to short summer season and this need to be sown in the crucial month of April or May. Crop cannot be fully matured if sowing is not done in proper time which ultimately gives low yielding crops. Considering the above facts and requirements in mind, locals have devised a unique system of water harvesting/conservation technique to augment water supply for irrigation. The artificial glaciers have been innovated and located as far as possible closer to the village and at lower altitude. It starts to melt much earlier as compared to a natural glacier. The melted water then collected in a small dam called as 'Zing'. These are small tanks, in which collects melted glacier water (17). Despite the small size, the potential for irrigated crop cultivation is determined by melt water from these glaciers.

Irrigation channel is built during November and December which divert/ guide the runoff water to the shady side of the mountain where it can slow down and freeze. In every terrain of the slope one retaining wall is made to slowdown the flow and makes it to freeze. Along this the flow below the frozen snow is also harvested and make it to freeze. Then the snow melted during April from which water supplied in Barley field for its first irrigation. This method is called Thachus.

TABLE-4:
STANDARDIZED IRRIGATION SCHEDULING OF CROPS IN COLD ARID REGION

Irrigation schedules	Ladakhi name with saying	Field/ crop stages
Initial watering	Khaichhu	This is the first irrigation which is given after 20th October after harvesting which facilitates sowing of crops during April.
First watering	Tha-chus spit-la kha baps-nazying kha-ser-la song	Field is irrigated and left for 3-15 days (depending on the quality of the soil), wait for soil with right moisture, best suited for sowing (ser- phar-tog means gold is ready); if it is too damp, then it is called ser-lchin-te dug (gold is heavy).
Second watering	dol-chhu dol-chhukhyemthil-la ner-nertsug-pa chhuzyen-chuk	Second irrigation is applied around 15-20 days gap when the seeds have just sprouted with skillful care. Let the dol-chhu flow till the iron portion of the spade submerges in the water. (Germination stage)
Third watering	sak-chhu sha-gu-gang-ngi or nang gang-ngichhu	Third light irrigation is applied at 15-20 days gap after second when the crop has grown up to a height of about 13 cm (If denied, upper portion of the crop dries up). One sha-gu-gang-ngior nang gang-ngichhu (a channel full water) is released or development stage
Fourth watering	non-chhu	It is given 10-15 days after third watering when all the crop plants have grown to the same level at the time of flowering. From now onwards, the crop is watered regularly once a week, or about six times before the last watering, which is called do-chhu depending on the moisture in the soil and weather condition.
Fifth irrigation	Gep-chhu	This irrigation depends upon the color position of crop, if crop seems yellow colour, this irrigation be late. However, when color is blackish, this is required early. (seed setting stage)
Last watering	do-chhu	Application of do-chhu, meaning watering of fully- grown crop field is very important. If not watered, the ears of crop get dry and start falling. The web of irrigation system binds the Ladakhi villagers to each other and these reflect a shared source of life. However, the same web creates claustrophobic technique of surveillance by which villagers keep each other in check (Gutschow,1998).

5.6 STATUS OF THE GLACIERS IN THE CENTRAL LADAKH

Himalayan glaciers are receding faster than before. In Nang village, according to Tsering Wangdush, Sarpanch, Nang and others from the village of about 400 people, surrounding slopes used to be snow-covered all-year-round but due to temperature rise and climate change, now they have snow only at the top. Residents have created their own glacier to supplement the natural one. "Today, water from glaciers is practically unavailable during April and May, when it is needed the most. So, we created an artificial glacier closer to the village using excess glacial meltwater runoff during the summer. This would mimic a real glacier and provide water for irrigation during those two crucial months," says 81-year-old Chawang Norphel, the pioneer of artificial glaciers (18).

The specific combination of topography and climate contributes to the small size and high altitude of glaciers, almost all of which terminate above 5200 m. While the glaciated area of central Ladakh totals 997 km^2 with more than 1800 glaciers, 79% of them are smaller than 0.75 km^2. A general glacier decrease is evident for the time period between 1969 and 2016, with a high variability across different watersheds, with glaciated area reduction ranging from 0.2 to 0.9% $year^{-1}$ (19).

As per Agriculture census 1995-96 there are 123669 farms in Leh district with an average land holding of around 0.81 ha (14). About 61.6% farmers belongs to "less than one hectare" (20). Under such conditions, water flowing close to the villages, is shortly diverted to irrigate the fields and managed according to a traditional communal system for distributing water equitably and efficiently (6). Accordingly, the number of irrigations has significantly reduced; impacting crop growth and yield levels drastically reduced as mentioned in Table 5 and farmers have switched over to new crops for better livelihood options.

Even though biophysical resources especially water for irrigation is a crucial support affecting the agriculture system and determining patterns of land use. Land use from the original state of barley and wheat cultivation when every trickle of water was used to irrigation to support subsistence cultivation has transformed considerably. Production is for the market and a variety of vegetables are cultivated which are mainly purchased by the army (21).

irrigates the fields. The point from where togpo water is diverted into ma-yur, and ma-yur water into a yu-ra is called yurgo; and ska is the point from where yu-ra water is diverted to the field. Water in the ska is further guided through channels known as snang, which carry the water throughout the field. Water supply to individual families for irrigation is

TABLE-5:
NUMBER OF IRRIGATIONS UNDER PRACTICE AT DIFFERENT ALTITUDINAL VILLAGES OF LEH DISTRICT

Villages / Crops/ Vegetables	Actual position		Potential irrigation cycle by ice reservoir	Wheat*		Barley*		Potato*		Vegetables**	
	HH	Status with glaciated area (km^2)		W	Y	W	Y	W	Y	W	Y
Saboo	200+	Diversion irrigated (0.33)	0.13-0.32 0.41-1.03	8-9	2	8-9	1.5	8-9	6.45	3	1.67
Stakmo	45	Diversion semi-irrigated (0.03)	0.31-0.77 0.98-2.46	7	1.2	7	0.75	7	6.25	3-4	1.12
Nang	68	Diversion rain-fed	0.04-0.1 0.12-0.3	5-6	0.54	5-6	0.45	3-4	6.15	2-3	0.57
Chushot Gomma	1836	River	-	5	0.85	5	1.10	5	1.2	3	-
Thiksey	2237	River	-	6	0.8	6	2-3	-	-	3	-
Umla	18	Cascade	0.08-0.21 0.27-1.03						2.0	2	-
Upper Tukcha, Leh	-	Diversion +bore-well	-	10	0.5-0.7	10	0.5	10	2.0	4	-

W-numbers of watering; Y-yield q/500 sq m.
Potential irrigation cycles by ice reservoir volume: assuming that fields are flooded with 2–5 cm of water; upper range represents unfavorable years and cases, lower range represents optimal conditions;
****calculated by mean average ratio irrigated to cropped area**
Glaciated area: Source-Nüsser et al., (2019)

5.7 ART DESIGNED FOR COMMUNITY IRRIGATION

In community irrigation the irrigation water is managed by the local people of Phyang (upstream) and Phey (downstream) villages. Equitable and timely distribution of this water is the focus of the local institute for proper management of water. The system of water distribution is certainly complex but exploitation is rare. The Women's Alliance of Ladakh consisting of 4000 women in 113 villages are making efforts to protect Ladakh's environment and preserving their culture and even persuading farmers of the cold desert to practice organic farming and traditional water harvesting as farmers face water scarcity because of low snowfall in recent years (12).

Kangs-chhu (ice water) which is melted snow water from various rivulets at some point merges and forms a togpo (stream) that flows through a valley touching many villages connected by a main channel called ma-yur (mother channel). This channel is built along a mountainside that forms its retaining wall which acts as a dyke to hold thewater from the ma-yur is further diverted into yu-ra (small canals), which

supervised by a chhur-pon. The chhur-pon is an official, selected by the villagers, who is in charge of water distribution for irrigation and is perhaps the most important functionary in this regard (4). Community approach for distribution of water is very unique and honest. Every household gets glacier recharge water as irrigation at fixed schedule by informing each other timely (12).

Distribution of water to the right field on the appropriate day and time is the responsibility of the chhurpun or water manager. Some of the villages in Ladakh do not maintain Chhurpon system as they have abundance of water resources. The chhurpun in Ladakh, unlike in Tibet, is a village level office of a family (6). In times of scarcity the villagers follow the previously designed plan of which fields to be left fallow (6), (22), (23). The farmers have developed irrigation schedule matchingto the critical stages of crop growth for maximization of crop yield as well as water use efficiency (Fig. 4). Irrigations are generally scheduled on colour status basis of the crop (11).

5.8 Micro-irrigation

Among the ex-situ water conservation methods, in arid ecosystem, emphasis has been given mostly on pressurized irrigation system. In irrigation related problems micro irrigation system is considered as a panacea. In this irrigation system water is applied in the vicinity of the crop plants precisely without losses. It reduces irrigation water losses occurring through evaporation, conveyance, and distribution; therefore, high water use efficiency can be achieved. The use of micro-irrigation technologies becomes prevalent as it is a potential source for food production in cold arid high desert agro-ecosystem of Ladakh. It has been proved that up to 25% water can be saved if pressurized irrigation system is used as compared to conventional system. As indicated in Fig. 5, there are losses through various modes.

Fig.4. Field irrigation channels of community

It was unimaginable and not economical farming at world's highest peak in Himalayas (far away from main land) as availability of water & power / diesel was a big challenge. To switch over this technology towards green technology the solar powered drip irrigation is the potential to utilize the abundant availability of solar radiation in Ladakh. A novel approach of Integrated solution: solar pumping + micro irrigation made large scale farming feasible in cold desert which facilitates lifting of water from river and irrigate research farms and avoid cost of development & maintenance of distribution grid and monthly electricity bill.

Mulching: In Ladakh, summer season vegetable crops like cucurbits, tomato, brinjal, okra and capsicum etc. give better yield under mulching practices. It has been observed that Black polyethylene 150 gauge thick has good impact on the crops like cucurbits, tomato, brinjal, okra, capsicum and chilli (17).

6 Basic Needs

A farmer has to bear six factors in mind when he plans to irrigate his land. They are: The adequacy, reliability, and quality of the water supply; the control and conveyance of water; water requirements, including consumptive use, effective rainfall, net irrigation requirement, and irrigation efficiency; application of water; drainage for removal of both surface and subsurface excess water; and institutional arrangements.

Uncontrolled irrigation water can cause erosion. It can strip soil from bare sloping fields at an alarming rate: The very water that is so essential to crop growth can also be the means by which the land is ruined. Irrigation water applied improperly also causes segregation of the soil particles. The smaller particles are moved downslope and tend to increase the intake rate at the upper end and seal off the lower end of the field. Uniform irrigation throughout the field thus is harder to achieve. Proper irrigation and soil management will help prevent particle segregation.

Being cold arid region, the temperature ranges is between -35°C in winter to +35°C in summer. In general, area has short mild summer to long cold winter. Mean precipitation ranged between 100-120mm, the major portion of which comes in form of snow fall. Potential evapo-transpiration was in order of 700-800mm per year. The growing period varies from location to location, ranging from 80 to 150 days (from mid-April to August).

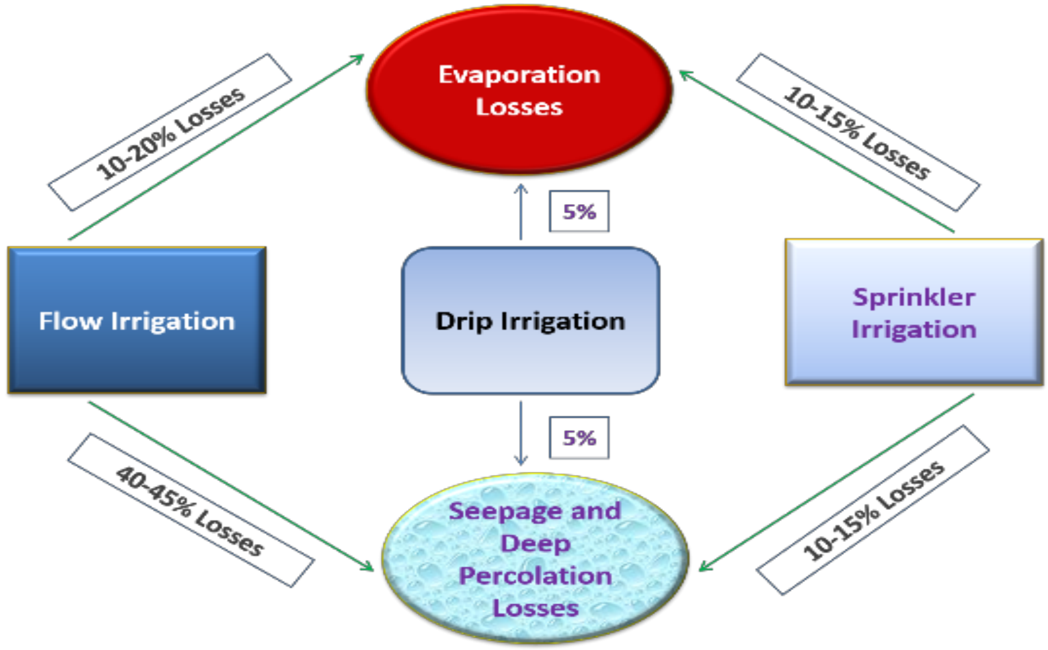

Fig.5. Losses of soil moisture.

7 CONCLUSIONS

Agriculture is the main stay of Ladakh economy and its full dependence is on glacier-melt water which is a social factor for its honest distribution under the hand of farming expertise-Chhurpon. Water for irrigation is one of the major natural resources for resource poor farmers of inherent vulnerability of subsistence agricultural communities of high altitude Ladakh trans-Himalaya. Receding glaciers make it very difficult even to sustain subsistence system of livelihood. Farmers are choosing other livelihood options and shifting to other easier way of agriculture i.e., from staple food to alfalfa fodder production, hence reducing area under food crops at higher pace. Adoption of location specific scientific interventions is the only ways to take bring back the Ladakh farming from subsistence to a sustainable and utilizing improved micro-irrigation technologies involving policy makers and LAHDC for betterment of irrigation developments. To tackle such problems, the people have to adopt modern water harvesting techniques such as artificial glacier, mulching, drip irrigation system for efficient use of valuable water resource. Also, more research should be carried out, mainly focusing on moisture conservation in cold desert condition Increasing the time of retention of water in reservoir, modification of zing to avoid the conveyance losses, promoting solar powered drip irrigation rationalised rotational system of community and irrigation, intervention of climate resilient irrigation management techniques, that enables farmers to minimise risks and/ or maximise profits under such harsh climates. It has also been recommended by Central Ground Water Board, 2012 that irrigation channels carrying water from higher reaches need to be maintained properly to maintain net water receipts; water harvesting ponds as recharge structure by constructing small ponds in every village; traditional resources like springs to be maintained and protected; deep tube wells of 100 to 120 m depth are recommended to be constructed for water supply in terraces underlain by moraine formations. Hand pumps of 70 to 80 m depth are also recommended in small hamlets to meet the water supply requirements.

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