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Weather prediction using traditional knowledge in cold arid high altitude region of Ladakh in India

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The Union territory of Ladakh in India is a cold arid high altitude region. The subsistence nature of agriculture being practiced (by majority of farmers) in the region is solely dependent on melted glacier water. The present study was undertaken in Leh district of Ladakh to identify, prioritize and understand the traditional knowledge (TK) used by the farming community for prediction of weather. The primary data were collected from 320 households from 20 villages in Leh district from 2015 to 2020. The primary data were aided and validated by Focused Group Discussions with key informants and stakeholders working in the region such as scientists from research institutions and officials from agriculture and line departments. Farmers used combination of indicators including behavioral changes of birds and animals, change in atmospheric events and inferences drawn from *Lotho* (almanac) to predict weather. Migration pattern of birds was the most ancient, common and widely prevalent TK used for prediction of onset and extent of snowfall and winter season by farmers. Building of nest by birds on poplar tree (*Poplus* sp.) at different heights and directions was used to predict temperatures in the forthcoming summer season. The duration of hibernation of Himalayan marmots (*Marmota himalayana*) was an indication of duration of snowfall and winter temperatures. Timing and extent of precipitation (rainfall and snowfall) was used to predict the distribution of snowfall and winter temperatures. *Lotho* was extensively used for planning agricultural operations till a decade ago. The farming community used different TK in totality to enhance the accuracy of weather prediction. It was found that improved connectivity of the region with the mainland, introduction of modern communication technologies and decreasing dependence on agriculture as a primary livelihood option (because of the emergence of non-farm based opportunities such as services and tourism) have made the use of TK less prevalent among young generation farmers. However, the majority of the farmers expressed the need for blending TK and modern science for addressing location-specific problems.

Keywords: Leh-Ladakh, *Lotho,* Migration, Traditional knowledge, Weather prediction

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Indian agriculture is primarily and heavily dependent on the weather. Weather parameters like rainfall, sunshine hours, temperature, relative humidity and length of the drought period affect the cycle-to-cycle variability of crop production. The uncontrollable nature of climatic factors is changing over a period of time affecting agricultural, economic, social and environmental sustainability. Different studies show an increasing trend in the average air temperature and more volatile rainfall patterns[1]. Rainfall is one of the most important climatic variables because of its two-sided effects: (i) as a deficient resource such as droughts and (ii) as a catastrophic agent such as floods. Based on numerous studies, it is expected to result in long-term water and other resource shortages, degrading soil fertility, disease and pest outbreaks on crops and livestock and so on, which will affect different crops differently. Farmers would incur losses, primarily due to reduction in agricultural productivity, crop yields and loss of farm productivity.

Indian agriculture is a gamble of monsoon. The accurate rainfall forecast will lower the risks associated with agriculture management and production. The rainfall forecasting in India is done through traditional as well as modern scientific forecasting methods. The Indian Meteorological Department (IMD) is presently giving short-term, medium-range and long or extended rainfall forecasting. The collaboration of IMD with

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the National Centre for Medium Range Weather Forecasting (NCMRWF) has adopted district level Agro-Advisory Services (AAS) for disseminating medium-range weather forecast information to farmers. However, the validity of such services disseminated to the district level has some limitations, particularly in view of the large variability in terms of crops, varieties and spatial weather anomalies at this level. Considering the variability of weather, climate and soil, the Indian Council of Agricultural Research (ICAR) through All India Coordinated Research Project on Agrometeorology (AICRPAM) has initiated dissemination of micro-level AAS through its cooperating centers spread across the country to enable the capacity building of farmers for climate resilience[2]. These AAS helped farmers in improving the productivity and farm incomes. However, the willingness to pay for these AAS was low for majority of farmers due to their farm resource constraints[3].

On the other hand, the traditional forecasting methods are based on the observations and experiences of the farming community over a period of centuries using combination of plant, animal, insect, bird, meteorological and astronomical indicators and through various mathematical calculation methods based on *Panchang* (almanac)[4-15]. Farming communities have evolved various Traditional Knowledge (TK) pertaining to agriculture, livestock, soil and water conservation, water harvesting, prediction of weather, storage, processing and value addition aimed at solving a particular problem while achieving a fine balance of efficiency and sustainability. The prevalence and use of such TK is higher in remote, drought-prone, resource-poor and climatically vulnerable areas. In this context, documentation and validation of the TK pertaining to the prediction of weather by farming community in the Union Territory of Ladakh, a cold arid high altitude region in the trans-Himalayas, India was attempted. The specific objectives deduced were:

(i) To document the TK pertaining to the prediction of weather by farming community in the Union Territory of Ladakh and

(ii) To understand the science behind these TK and their relative prevalence and use.

Methodology

Exploratory research design was adopted for the study. The study was conducted in the Leh district of the newly formed Union territory of Ladakh. Leh district was purposively selected for the study due to its remoteness and prevalent harsh environmental conditions. Twenty villages were selected for the study using stratified sampling technique to represent different parts of Leh district. The 320 households from these 20 villages were randomly selected for the collection of primary data. The details of the villages selected for the study are provided in Table 1. As many of the questions were open ended in nature, on most of

Table 1 — Brief demographic profile of study villages and sample size

Sl. No.	Name of the village	Altitude (Ft AMSL)	Population	Number of households in the village	Sample Size of respondent households
1	Saboo	12276	1233	259	25
2	Stakmo	12303	263	45	12
3	Phey	10654	331	57	13
4	Nimoo	10432	1134	193	19
5	Phyang	12265	2036	550	24
6	Shey	10962	2238	398	22
7	Nang	12396	334	74	16
8	Ranbirpur	10958	594	122	22
9	Thiksey	10370	2237	423	24
10	Tsogsti	11628	38	5	3
11	Umla	12303	99	21	9
12	Chushot Yokma	11056	2162	428	22
13	Basgo	10387	950	172	21
14	Martselang	11161	381	69	13
15	Matho	11716	1165	279	19
16	Stok	11703	1471	300	21
17	Changa	11173	243	58	9
18	Taru	12093	442	71	12
19	Shyang	13100	230	51	9
20	Skara (Leh Urban)	11562	950	210	5
	Total		**18531**	**3575**	**320**

Note: The population of villages is as per Census 2011.

the occasions, the key informant in the household was aided by other family members and a single household was taken as a unit for data collection. Apart from this, a minimum of one Focus Group Discussion (FGD) was conducted in the selected villages to aid upon the collected data, which also helped verify the data from individual households.

Ladakh is a cold desert region in the Western Himalayas at altitudes ranging from 10,000 to 14,000 feet AMSL. Leh district, scattered on an area of 82665 Sq. Kms, is the largest district in the country having 112 inhabited and one uninhabited villages with a population of 133487 souls as per 2011[16].

The list of TK pertaining to the prediction of weather and climate by farmers in Leh district was prepared based on the extensive review of literature, discussion with experts and pilot study conducted in the study area from May 2015 to October 2016.

A semi-structured interview schedule was developed specifically for the study. The primary data were collected by personally interviewing 320 respondents (households) between May 2015 and February 2020. The respondents were explained about the objectives of this research study and their prior informed consent was taken before collection of the data. The agreement of the respondent on each of the TK was recorded. Concordance Percent was calculated to measure the overall agreement of the respondents on each TK. Concordance Percent is the ratio of respondents who agreed with the statement on TK to the total number of respondents (= 320) multiplied by hundred.

FGDs were held with key farmers, *amchis* (traditional healers) and other stakeholders working in the region such as scientists from High Mountain Arid Agriculture Research Institute, Leh; Defence Institute of High Altitude Research (DIHAR), Leh; and Department of Agriculture and its line departments to validate the primary data. Visits were made to agriculture and non-agriculture fields (community property resources such as grazing lands) in the study area to acquaint with the farming systems and practices. Plants and birds were identified with the help of respondents and their English and scientific names were thereafter confirmed. The personal interviews, group discussions and field observations were made by interdisciplinary team of scientists/ researchers (working in the area of meteorology, agricultural extension, agronomy, agro-forestry, agricultural entomology and soil science) from ICAR-Central Arid Zone Research Institute, Jodhpur and its Regional Research Station at Leh.

Results and Discussion

Due to harsh winter and heavy snowfall, Ladakh remains cut-off for almost seven months (from October-May) from rest of the world by surface transportation. The region experiences mean annual precipitation of 80-300 mm and an extremely harsh climate during winter (-30°C). The agriculture is predominantly subsistence oriented and completely dependent on glacier water for irrigation[17,18]. The land holdings are small, fragmented and located at different altitudes. The region has only one crop growing season (May-September) and the principal crops are wheat, barley, alfalfa/ lucerne and vegetables. Livestock, horticulture and agro-forestry are essential components of farming systems in the region.

Adaptation strategies and behaviour of birds to understand/ predict weather phenomena

The behavioral adaptation strategies of birds to mitigate extreme weather conditions in Ladakh region have been used by farmers as indicators for prediction of rainfall/snowfall and consequent change in temperatures. The behavioral changes of birds and animals were observed and correlated by the farmers and residents of the region over centuries and are in practice even today (Table 2).

The main climatic features of cold desert of India are wide diurnal and seasonal fluctuation in temperature with –40°C in winter and +35°C in summer, very low annual precipitation of 10 cm mainly in the form of snow, very dry air and relative humidity ranging from 6-24%[19,20]. Analysis of meteorological data of Leh for 35 years indicated a rising trend of minimum temperature with nearly 1°C increase in the winter and 0.5°C rise in summer temperature[21].

Birds avoid extreme cold climate through migration. Birds undertake migration within the region and between the regions. Birds migrate within the region between mountains (high altitude) and village/plain areas (low altitude). Movement of birds (*Richi or Ri Ichu, Srakpa, Lak, Chunka, Ribja*) from village to high mountains indicated onset of summer season. Return of birds from mountains to villages indicated occurrence of snowfall on mountains and onset of winter. Birds also migrated from Leh-Ladakh region towards the lowland warmer regions during harsh winter season. Out-migration of birds (*Chipa Gyao*) from village indicates onset of winter. Return of these birds from migration/ in-migration to villages indicates onset of spring season (March-April).

Table 2 — Behavioral adaptation strategies of birds used to predict weather N=320

Sl. No.	Statement	Agree	Don't know	Concordance Percent
		f	*f*	
I	Migration of birds			
1	Out-migration of birds (sparrow/ *Chipa Gyao*) from village indicates onset of winter season.	286	34	89.38
2	Return of birds from migration/ in-migration to villages indicated onset of spring season (March-April).	286	34	89.38
II	Movement of birds between mountains and lower valleys			
1	Movement of birds (*Richi, Srakpa*, Lak, *Chunka*, *Ribja*, *Chipa Gyao*, *Sintik* and *Tsilder*) from village (lower altitude) to high mountains (higher altitude) indicates onset of summer season.	286	34	89.38
2	Return of birds from mountains to villages indicated occurrence of snowfall on mountains and onset of winter.	286	34	89.38
III	Building of nest by birds (Magpie, *Chipa Gyao*, *Katang putit*, *Tsilder*) on poplar/ other trees at different heights			
1	Nest building at top of the tree predicted relatively high temperature in the coming summer season.	263	57	82.19
2	Nest building at medium height indicated relatively moderate temperature in the coming summer season.	263	57	82.19
3	Nest building at lower height indicated relatively cool summer season ahead.	263	57	82.19
4	Building of nests on seabuckthorn (*Hippophae rhamnoides*) indicated relatively higher snowfall on mountains and severe winter.	207	113	64.69
5	Building of nests by birds near crop field in sixth month of *Lotho* (local almanac, where it's sixth month falls somewhere in July-August) indicated that crop is at peak season.	156	164	48.75
IV	Variation in bird population			
1	Relatively higher bird population (sparrow) in winter (compared to good snowfall years) indicated low snowfall and vice versa is true.	252	68	78.75
2	Higher bird population (*Chathao)* in winter indicated relatively cool summer.	247	73	77.19
V	Sounds (songs and calls) made by birds			
1	Low husky call/sound "*Utu-Tuk*" call made by *Hututusay* indicates onset of winter and alarm of freezing temperature.	217	103	67.81
2	High pitch voice "*Uchuchu*" made by Hoopoe (generally made somewhere in first week of May around Leh area) indicates onset of agricultural season (including wheat sowing).	217	103	67.81

Note: (a) The vernacular, common and scientific names of the birds mentioned in the Table 2 are provided in Table 6. (b) None of the farmers disagreed with any statement in Tables 2, 4 and 5.

Building of nest on poplar tree (*Poplus* sp.) by birds like Magpie, *Khata thao and Tsilder* at different heights indicated the extent of snowfall to be witnessed. Nest building at top of the tree predicted relatively hot summer season ahead, whereas nest building at medium height indicated moderate temperature in upcoming summer. Similarly, nest building at lower height indicated relatively cool summer ahead. Farmers explained that birds build nest at top of the tree to avoid relatively higher temperature at ground level in summer. *Poplus nigra* (black poplar, locally called Yulad or Yulat) is found grown in the Indus plains, whereas *Poplus balsamifera* (Balsam poplar, locally called Yarpa or Berfa) is generally found in valleys. Building of nests on Seabuckthorn (*Hippophae rhamnoides*), a shrub, indicates higher snowfall on mountains and severe winter.

Forthcoming weather affected construction of nest by birds at different heights on poplar tree. The construction of nest in the month of October indicated weather for the forthcoming season (October-April). The height of nest constructed on a particular poplar tree in Skara village was recorded in the month of October. In 2014, the nest was constructed at 14.5 meter from the ground indicating warmer season ahead. The observed mean air temperature was higher

Table 3 — TKS-Validation of nest building and weather prediction indicators in Ladakh region

Year	Height of nest from ground (Meters)	Duration	Monthly mean of daily T_{max} (°C)	Monthly mean of daily T_{min} (°C)	Monthly mean of daily Temp (°C)
2014	14.5	October 2014 to April 2015	10.9	-4.2	3.4
2015	12	October 2015 to April 2016	10.7	-4.3	3.2
2016	9.5	October 2016 to April 2017	8.1	-5.3	2.2
2017	8	October 2017 to April 2018	-	-	-

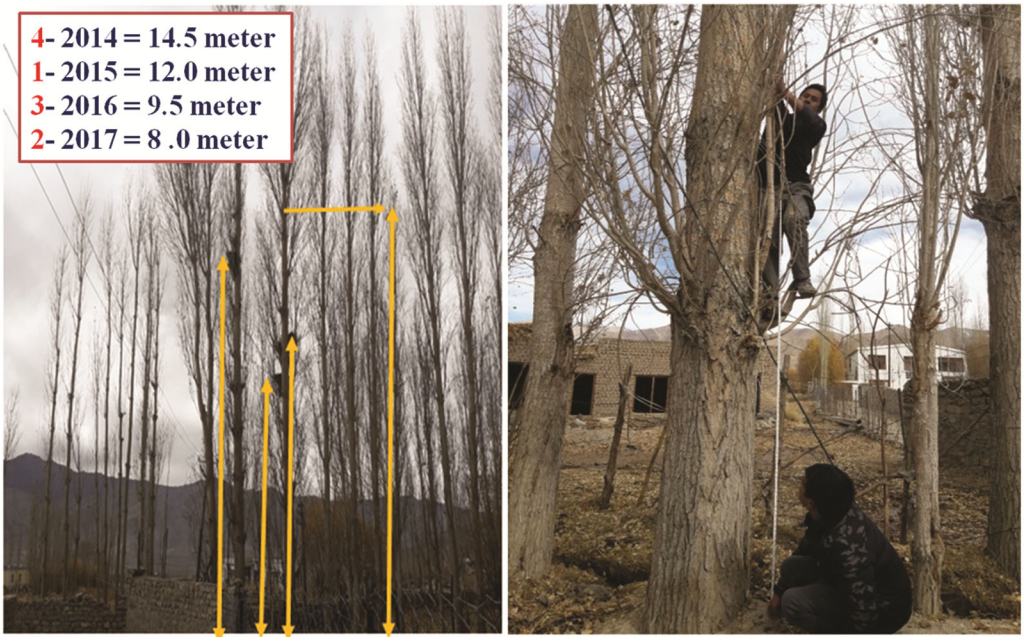

Fig. 1 — Building of nest on poplar tree by magpie bird at different heights in different years at Skara village

during the season (Table 3) as compared to the years in 2015 and 2016 when the nest was observed at 12 and 9.5 meters respectively from the ground (Fig. 1).

The population of birds was used to indicate the extent of snowfall. Relatively higher bird population (sparrow) in winter (compared to bird population during years witnessing severe winter) indicated low snowfall and vice versa was true. Relatively higher population of some birds (*Chathao*) in winter indicated relatively cool summer in the upcoming season. The extent of snowfall in winter affected migration of birds and consequently their population. All the respondents agreed that migration of birds was observed and used to predict weather over generations.

The songs and calls made by birds were also used to predict the weather. Low husky call/sound "*Utu-Tuk*" call made by *Hututusay* bird indicated onset of winter and alarm of freezing temperature. High pitch voice "*Uchuchu*" made by Hoopoe in first week of May indicated onset of agricultural season. Farmers reported that this bird makes different calls during different seasons, which only experienced farmers can correlate with different upcoming changes in seasons.

The concordance percent was highest on TKs pertaining to the prediction of weather based on the migration of birds (89%) and building of nests by birds on poplar trees (82%) indicating that this knowledge was developed and passed on over generations and widely used by the farming community in the region. The migration of birds and nest building on poplar trees are processes that farmers and farm women observe every year in their homesteads and neighborhoods. The correlation between these activities and changes in weather was direct and observable. The concordance percent was low (68%) in the case of TKs pertaining to the prediction of weather using the songs and calls made by birds. It may be because of the fact that sounds made by birds are determined by many factors among which weather is one factor, and moreover, their interpretation can only be done by an experienced and expert individual.

Table 4 — Behavior of animals used to predict weather N=320

Sl. No.	Statement	Agree	Don't know	Concordance Percent
1	Movement of marmots outside their burrows in the third month of *Lotho* (April-May) indicated onset of spring season.	273	47	85.31
2	Going into hibernation of marmots (into deep burrows) in the month of October indicated onset of winter.	273	47	85.31
3	Appearance of deer near villages (low altitude) during peak winter indicated higher snowfall in mountains.	255	65	79.69
4	Resting of deer under bright sunshine during winter indicated higher snowfall in mountains/highland areas.	238	82	74.38
5	Visit of wild animals (Ibex, deer) to villages for grazing grass in the 5th month of *Lotho* (June-July) indicated peak summer.	227	93	70.94
6	Building of nest/colony/hill by ants predicted occurrence of rainfall.	215	105	67.19
7	Development of fog in and around water sources such as river, streams, etc. at the beginning of winter indicated more snowfall and severe winter.	254	66	79.38
8	Accumulation of frosts on door and roof of house in 11th or 12th month of *Lotho* (December/January) indicated extreme cold. Frosts appear in the morning and evening during peak winter (December-January) indicated high snowfall/severe winter.	261	59	81.56
9	Blaring and fast running of Dzo, Yak and cows indicated expectation of precipitation, mostly snowfall within one or two days.	94	226	29.38
10	Blaring/ screaming of dzo, cow and cattle during October-November months indicated snowfall within one day.	100	220	31.25

Behaviour of domesticated and wild animals to understand/ predict weather phenomena

The behavior of animals is also being used to predict weather by the local farmers of Ladakh (Table 4). As the severe winter sets in, Himalayan marmots (*Marmota himalayana*), locally called as *Phya*, go into hibernation in long and deep dugged burrows. As the winter season is over and the temperature starts to rise, these hibernated marmots come out of their burrows, indicating onset of summer. Similarly, wild animals such as deer and ibex come down from mountains to villages whenever there is heavy snowfall on the mountains for grazing on plains. The concordance percent was highest on TKs pertaining to the prediction of weather based on hibernation behaviour of marmots (85.31%) and movement of wild animals (71-80%). Farmers reported that blaring and fast running of *Dzo* (a crossbreed between yak and cow), yak and cows indicated expectation of precipitation, mostly snowfall within one or two days. Blaring/ screaming of dzo, cow and cattle during October-November months indicated snowfall within one day. However, the concordance percent on these TKs was low (29-31%) indicating low reliability and usage.

Use of *Lotho* (Tibetan almanac) to understand/ predict weather phenomena

Traditionally, farmers followed all agriculture practices in Leh Ladakh region based on the astronomical facts of the Tibetan Almanac called "*Lotho*". The *Lotho* has 24 stars with a 14-15 days period for each star. The first star starts in the end of February. The *Lotho* has mathematical-based prediction of weather phenomenon and was used as a guide for planning various agricultural operations. The appearance of *Sakha-Dava* star in 2nd month of *Lotho* (March-April) indicated right time for onset of field preparation (CP=67.5%). Appearance of *Skarma Wa* (eighth star) indicated possibility of rain/cloudy days (CP=67.5%). Appearance of *Skarma Chama* star in 8th month (September) indicated equal duration of day and night and occurrence of rainfall (CP=67.5%). The appearance of *Skrama-Tanya* star in 3rd month of *Lotho* (April-May) indicated delay in the onset of agriculture practices by 12 days (CP=67.5%). Therefore, the appearance of this star was used to take the decision regarding the choice of crops and varieties for sowing. Wheat is sown before the appearance of this star and barley (*Shirok* variety) was sown when the star has appeared. Similarly, the appearance of *Wachar* star in 6th month (July-August) indicated heavy rainfall and cold and cloudy weather (CP=60.6%). Key informants/ experts reported that this star was noticed in 2010 and high intensity rains were predicted. There was flash flood in 2010 that ravaged the Leh district. Farmers associated the appearance of this star with high-intensity rainfall leading to crop damage. Appearance of *Stachn* in 6th

Table 5 — Change in atmospheric events used for prediction of weather N=320

Sl. No.	Statement	Agree	Don't know	Concordance Percent
1	Snowfall on trees (common species are Salix and poplar) with green leaves still intact (September-October, before the tree goes into hibernation) indicated low snowfall in the coming winter accompanied by warmer winter temperature.	242	78	75.63
2	Rainfall during summer months indicated good snowfall in coming winter.	224	96	70.00
3	Snowfall during second fortnight of October indicated good snowfall in next season and winter will start in around December.	186	134	58.13
4	Snowfall during summer on the higher peaks (May, June and July) indicated poor highland pasture for livestock and wild animals.	186	134	58.13
5	Appearance of rainbow indicated no rainfall and clear weather for next few days.	80	240	25.00
6	Black clouds indicated rainfall on the same day.	76	244	23.75

month (July-August) indicated low rainfall or end of rainfall season (CP=52.2%). Appearance of *Tha* star in 8th month (September) indicated light rain at high altitude (CP=28.4%). The concordance percent on use of *Lotho* for prediction of weather varied from 28-68% indicating low to moderate reliability of these TKs by the present generation. Shri Skalzang Tundup, Thiksey village; Shri Sonam Tundup, Stakmo village; Shri Ghulam Rasool and Smt Zenab Parveen, Aayu/ Saboo village, and Shri Takpathayas, Phey village are some of the local experts on the interpretation of Lotho. These experts and elderly farmers reported that farmers relied more on *Lotho* for planning agricultural operations till 10-15 years ago. Better connectivity with the mainland and the introduction of modern weather forecasting methods has slowly rendered these TKs less common in practice. Although, *Lotho* is still prevalent and very common in finding auspicious dates for taking up any cultural, religious and social ceremonies by the Buddhist community of Ladakh region.

Referring to the *Lotho,* the prediction of rainfall by using Tibetan astrological theories (namely *Drupa* and *Tsepa*) are, on an average, goes hand in hand and in some cases at par with the predictions made by the government meteorological departments with modern techniques and procedures. The modern meteorologist should take advantage of astrological lore available in ancient books and memories of traditional or tribal people and combine it with their studies, so that a more reliable forecast could be offered for good of the people[6].

Change in atmospheric events to understand/ predict weather phenomena

Atmospheric events were also used to predict weather phenomenon (Table 5). Trees in Ladakh are deciduous in nature and generally shed their leaves during winter. However, the early onset of snowfall, when the trees are still covered with green leaves (snow falling on green leaves) indicated low snowfall in the winter season and subsequent high temperature. The concordance percent of these TKs were relatively high (70-75%) indicating high prevalence and use of these TKs. The onset of snowfall at right time (second fortnight of October) indicated good snowfall in the entire season. Change in leaf colour from green to yellowish indicated the onset of snowfall. White patches were observed on the ground by farmers during morning and evening hours due to frost or moisture converted into ice, indicating onset of winter season. Similar predictions based on weather phenomenon are also reported by various other authors. The flowering and emergence of new leaves in *Ficus species* indicates near rainfall onset[11]. For the elders among the tribal community of Rajasthan *"Sukarwar ri badri, rahi shanichar jaye, barsa bina na jaye",* which means that "If clouds are formed on Friday and remains until Saturday, then there is surety of rain[5]. A study conducted in Dindigul district of Tamil Nadu state reported that if lightening occurs from east, west and south, expect rain immediately. If lightening comes in an opposite direction (east to west) expect rain in another one hour[22]. The appearance of red sky at southwest direction indicates rain within 18 days. If rainbows appear in eastern side there would be chance of drought and if it appears in western side indicates sure rain[10].

Farmers also correlated the flowering of different plants with different seasons. Blossoming of *Tserma menthok* (Sea buckthorn) flowers indicated the onset of summer and the blossoming of *Tasmaey menthok* (*Iris* sp.) indicated the onset of the spring season.

The scientific names of the birds mentioned in the article are provided in Table 6.

Table 6 — Scientific names of the birds mentioned in the article

Sl. No.	Local Name	Common Name	Scientific Name
1	*Chipa Gyao*	Sparrow	*Passer domesticus*
2	*Hututusay/ Utu-tuse*	Hoopoe	*Upupa epops*
3	*Katang Putit/ Khata thao/ Chathao*	Magpie	*Pica pica*
4	*Tsildir*	Robin Accentor	*Prunella rubeculoides*
5	*Sintik*	Redstart	*Phoenicurus erythrogaster*
6	*Chunka*	Chough	*Pyrrhocorax pyrrhocorax*
7	*Nangpa*	Bar headed Goose	*Anser indicus*
8	*Richi/ Ri Ichu*	Tibetan snowfinch	*Montifringilla adamsi*
9	*Srakpa*	Partridge	*Phoenicurus ochruros*
10	*Lak*	Eagle	*Aquila nipalensis*
11	*Ribja*	Snowcock	*Tetraogallus himalayensis*

Analysis of different TK revealed that migration of birds was the most ancient, common and widely used TK for prediction of onset and extent of snowfall and winter season by farmers in Leh district. Farmers in the study area also reported a widely held belief that birds migrating from the region carry barley seeds and while returning from plains carry rice seeds. It indicated that birds migrated from the region when the cropping season in Leh region ends (harvesting of barley is done by the end of September in Leh region) and before the onset of snowfall (first fortnight of October). Birds return back to the region when the cropping season ends in plains (harvesting of rabi/winter season rice crop by end of February or March). The building of nests by birds on poplar trees at different heights and directions was also widely used to predict the weather. The hibernation of marmots was an adaptation strategy to escape harsh winters. The duration of the hibernation was an indication of the duration of snowfall and winter temperatures. Extent and timing of precipitation (rainfall and snowfall) were also widely used TK to predict the weather. The average precipitation rainfall in the region is 100 mm[19,20] and is too low to sustain agriculture. The cropping system is completely dependent on melted glacier water. Therefore, timely onset of snowfall, its duration and total quantity plays a major role in deciding the successful cropping season in the forthcoming agricultural year. Early snowfall, delay in snowfall, irregular distribution, early withdrawal and too low snowfall in the winter season have a bearing on the weather and consequently on the livelihoods of the farmers in the region. The use of *Lotho* for planning agricultural operations was widely used TK till a decade ago.

It is to be noted that farming community used different TKs in totality to predict weather, which enhances the accuracy of prediction. Various other factors also affected the accuracy of the prediction of weather. Experience and interest of the farming community as a whole in observing and using these TKs also affected the accuracy of the prediction. It was found during the study that old aged farmers (mostly above 60 years of age) were interested in these TKs because they used these TKs when they were young farmers. TKs were passed on from their ancestors and carried lot of significance in their way of life. The interest in TK among the young generation was low because they had moved out of agriculture in search of other employment opportunities in the region (mostly services and tourism sector). Even those young farmers who were practising agriculture had other (non-farm) income sources making agriculture a secondary occupation in terms of household income. Climate change is another factor which has affected the accuracy of the prediction of weather by farmers in the region. Climate change has led to an increase in the irregular distribution of precipitation and increase in temperature in the region. Farmers reported that for instance, the appearance of *Wachar* star in 6th month of *Lotho* (July-August) indicated heavy rainfall (chances of flood and erosion) and cold and cloudy weather. Nowadays, farmers associated the appearance of this star with high-intensity rainfall leading to crop damage.

Improved connectivity with the mainland and the introduction of modern communication technologies (including weather forecast by IMD and other organizations) have further made the use of TK less prevalent among young farmers. However, the majority of the farmers felt that there is a need for blending of both TK and modern science. Weather forecast by IMD works well at the regional level and TK takes into consideration the variations at the village/micro level.

Conclusions

The practice of agriculture for majority of farmers (except those residing in and around the cosmopolitan Leh city) in the Ladakh region is subsistence oriented and is solely dependent on the melted glacier water to irrigate their fields. The principal source of the glacier water is the precipitation (snowfall during winter formed into glaciers). The TK used by the farming community for prediction of weather in Leh district of Ladakh was documented in the study. Farmers used combination of indicators including adaptation strategies of birds and animals, change in atmospheric events and *Lotho* (Tibetan almanac) to predict weather. The concordance percent of different TK indicated the prevalence and relative use of these TKs by the respondents. The scientific explanation behind each TK was validated by discussion with different stakeholders including key informants, researchers and officials of agriculture and line departments. This study provides many hypotheses for such research studies in future and in-depth scientific studies into each of the TK documented in this study may further scientifically validate the TK. Further, weather forecasting by scientific organizations needs to integrate these TK in developing location-specific forecasts and agro-advisories after scientific validation.

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Conflict of Interest

The authors declare that no conflict of interest exists.

Authors' Contributions

HMM: Conceptualization of idea, development of data collection tools, primary data collection, Writing – original draft, review and editing; BLM: Funding acquisition, development of data collection tools, primary data collection, secondary data collection, data analysis, Writing – original draft, review and editing; MSR: Funding acquisition, primary data collection, Writing – review and editing; AV: Primary data collection, Writing – original draft, review and editing; DA: Secondary data collection, aiding and validation of primary data, Writing – review and editing; ND: Primary data collection and secondary data collection; and ES: Primary data collection and secondary data collection.

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