GEOGRAPHICAL ANALYSIS

RESEARCH ARTICLE

Climate Change Impact on Leh, A Glacier – Reliant Town: Adapative Responses, Impacts, and Solutions

R Shiva Kumar[1], **Padma Yangchan**[2]

1 *Guest Faculty, Department of Geography & Geoinformatics, Bangalore University, Bengaluru*
2 *M.Sc in Geography, Department of Geography & Geoinformatics, Bangalore University, Bengaluru*

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Abstract

It is an apparent and now well-documented fact that climate change and water cycles are closely interrelated. This study focuses on the effects of climate change on water supplies in the Ladakh region. Snowfall and glacial retention change in groundwater resource levels, unpredictable rainfall patterns, and coping with the resulting water scarcity are the area's current major problems. The main sources of water are the Himalayan glaciers, streams, springs and hand pumps that draw up water from the groundwater table. Climate change and resultant temperature rise have caused rapid melt water runoff in Ladakh, while erratic rainfall & groundwater vulnerability has reduced water supply. Climate change due to the rapid urbanization and global cycles of weather is not the only problem that the locals have to deal with. The high and naturally arid climate of the area has forced residents to acclimatize and adapt to difficult weather circumstances, including frigid winters, water scarcity, soil erosion, and various other natural hazards.

Keywords: Climate change; Groundwater; Natural glacier; Artificial glacier; Solar greenhouse

Introduction

Climate change is a global issue. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time" (UNFCCC, 1992). Cities and towns all across the world will be affected by climate change. Most scientists agree that the world has already experienced significant warming as a result of prior greenhouse gas emissions, and that the consequences of this warming are now being felt. As a result of climate change, millions of people living in urban areas face an immediate and long-term water crisis. When looking at the areas of the world that will be impacted by climate-induced water scarcity, it becomes clear that areas that rely on snowmelt are particularly vulnerable.

Due to the melting of bigger permanent glaciers caused by warmer winter and spring temperatures, some hydrological systems are seeing enhanced runoff and earlier peak discharge in rivers.

This melting of permanent glaciers could last all summer, resulting in increased discharge.

In the case of the Himalayan glacial system, there is still a lot of ambiguity about how the Himalayan snow-pack and glaciers will react to climate change.

Review of Literature

A significant number of studies in the domains of Glaciology and hydrology has been conducted in Ladakh. Peer-reviewed articles and conference presentations are the most common ways to obtain such scientific knowledge for a certain field.

Goldsmith, (1998); Norberg-Hodge, (2000), have studied the impacts of climate change that the local inhabitants have to face along with other issues of the high and arid environment of the region.

Eriksson, et al. (2009), studied the literature on glacial systems which shows that there are substantial gaps in the science of climate change and its effects on Himalayan glacial and hydrological systems.

Dimri and Dash, (2012); Shekhar et al., (2010), have written that over the Himalayan region, changes in temperature and precipitation patterns and it impacts on water resources, glaciers, ecology and agriculture etc. are being attributed to the changing climate.

Geneletti & Dawa, (2009), in their paper have studied the impact of cleaning detergents and chemicals on glacier melt water and the pressure on water from unplanned bore wells and tourism is having knock on effects for the delicately balanced agricultural regime which has been in place for centuries.

Le Masson and Nair, (2012), wrote that there are very few climate studies conducted over Ladakh/Leh. Bhutiyani et al. (2007) showed increasing temperature trends over Leh for the period of 1901-1989, with greater increase noted after 1960s. Precipitation trends show a decreasing trend during winter and summer periods.

Haeberli & Zemp, (2009); IPCC, (2007) have studied the impact of Climate change on the Cryosphere leading to the melting of glaciers and areas of permafrost. Bhutiyani, Kale, & Pawar, (2008) have written about the combined effects of glaciers melting, less snow storage and changes in precipitation, which will deeply affect the hydrological systems throughout mountain ranges. Mishra & Angmo, (2009) have made a report that if annual temperatures are rising and snowfall decreasing, glacial cover will diminish impacting on water availability in streams, springs, and groundwater.

A.Chevuturi et al. (2010), uses different temperature and precipitation data sets over Leh and surrounding regions, and statistically analyses the current trends of climatic patterns over the region. The study shows that the climate over Leh shows a warming trend with reduced precipitation in the current decade.

Study Area

This paper focuses on the Ladakh region (Figure 1). Ladakh was chosen as a case study because of its sensitivity to climate change. Throughout the world, mountains serve as indicators of climate change. The Himalayas consist of the Pir Panjal, Great Himalayas, Zanskar, Ladakh, and Karakorum ranges. Ladakh is located in India's northernmost state, Jammu and Kashmir, and is part of the Ladakh range. Ladakh is located between the Karakorum and Himalayan ranges, spanning 32–15–36–0 N latitude and 75–15–80–10 E longitude. With an area of 96,701 km2, of which 27,555 km2 is shared with Pakistan and China. As such areas have limited water resources, they are particularly vulnerable to climate change and need immediate action.

Ladakh, located in India's far north-western tip, occupies a unique physiographic, climatic, and cultural niche. It is distinguished by steep ranges, rock-faced mountains, barren ridges, glaciers, and snow fields, and is a cold desert. India has a 3.87 million km2 dry zone, with 27.8% of it in the frigid Western Himalaya and the remainder in the hot Western Gangetic plains and Peninsular India.

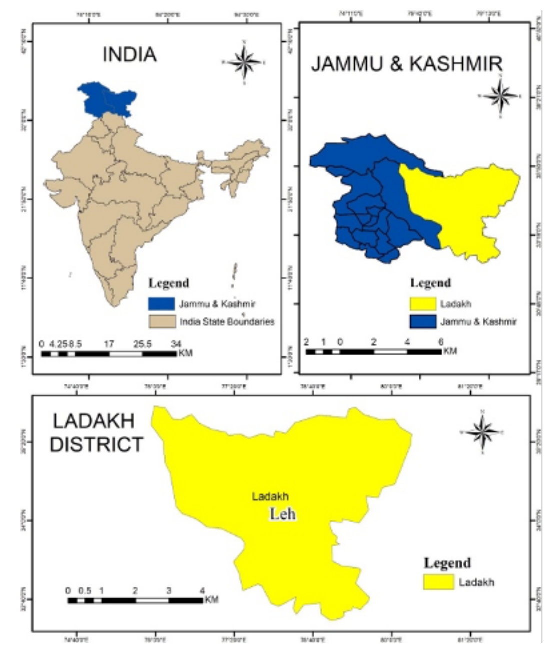

Fig. 1. Location map for the region of Ladakh in the Indian state of Jammu and Kashmir

Objective

The study's major intent is to better understand the climate of the Himalayan cold desert region, with a specific focus on Ladakh, and to define its changing environment and analyse the causes and conditions for it. Furthermore, the temperature and precipitation records over Leh from 1973 to

2008 were statistically analyzed to explore the current trends of climatic patterns over the region in order to determine the probability of changing climate in terms of temperature and precipitation patterns.

Methodology

A review of relevant existing literature was conducted on the northern Indian town of Leh, Ladakh from 1973 to 2008 in order to better understand the effects of climate change on glacier-dependent communities' water resources. Based on secondary sources such as articles, journals, and research papers, we synthesize information on climate change and its impact on water availability in the Ladakh region in this study. Comparative global data for similar mountainous regions was also analyzed to understand patterns and trends. Meteorological data is analyzed over time to corroborate the stark reality of climate change occurring in the region. Data from the meteorological department (Field Research Laboratory, Leh) were analyzed for 36 years (1973–2008) to determine the trend in temperature and precipitation. Temperature trends were examined during peak winter and summer months and through extrapolation correlations with other climatic factors and global trends were inferred & established. Using the variation in temperature and change in precipitation, the water resource availability and consumption were evaluated and community-based adaptions and policy-based changes were documented.

Description of Climate in the region

The region is characterized by deep gorges, deserts, and plateaus. The elevation ranges between 2,400 m and 8,500 m. The soils in Ladakh are coarse-textured, shallow, and sandy, with high permeability and low water-holding capacity. Snow covers the region for 7–8 months of the year, with the remaining months being the only ones that are productive.

Ladakh has a climate that differs significantly from the rest of the Indian subcontinent due to the Himalayan ranges that surround it. Ladakh, located north of the Himalayan watershed, experiences no summer monsoon and receives less than 7 cm of annual rainfall, making it one of the world's coldest deserts. Temperatures can drop to minus 45 degrees Celsius in the winter and fluctuate from 10 to 20 degrees Celsius in the summer. Summer in Leh lasts from May to August, followed by winter, which lasts until April. The town receives only a few inches of rain per year (50–200 mm), with most of it falling in July and August. When not covered in snow, the environment of Ladakh consists of harsh, barren granite mountains with little vegetation. The air in Leh is extremely dry, with relative humidity ranging from 6% to 24%. Leh receives a lot of solar radiation due to its high altitude; as a result, even if the temperature rarely exceeds 28° Celsius in the summer, the sun's strength is greatly enhanced by the rarefied atmosphere. Figure 2 depicts the annual temperature profile of Leh. Despite the difficult conditions, the region has been inhabited for millennium, and its people have managed to thrive by creating a synergistic relationship with their surroundings.

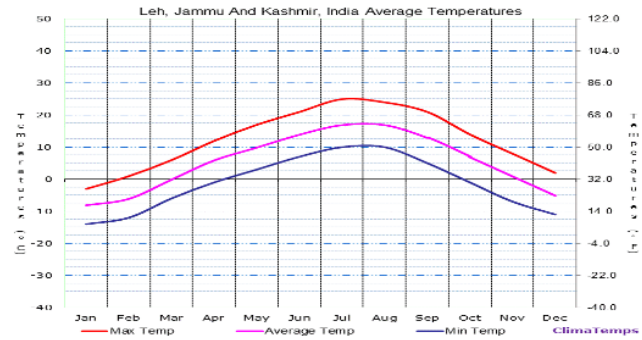

Fig. 2. Annual Temperature Profile of Leh

Climate Change and its Impact in the Region

Most Himalayan glaciers have been melting at rates ranging from a few meters to several tens of meters per year as a result of global warming (Hasnain 2002). Glaciers and ice cover around 17% of the broader Himalayan region, totaling nearly 1,13,000 km2, making it the biggest area covered by glaciers and permafrost outside of the polar regions. It is the source of nine of Asia's biggest rivers, the basins of which are home to roughly 1.3 billion people. Climate change has had a significant impact on the glacier ecology. Glacial melt will have a major negative impact on freshwater flows, affecting drinking water supply, biodiversity, hydro power, industry, agriculture, and others, with far-reaching consequences for the inhabitants of the region.

Meteorological data was reviewed over time to corroborate the stark truth of climate change occurring in the region. Data from the meteorological department (Field Research Laboratory, Leh) were analyzed for 36 years (1973–2008) to determine the trend in temperature and precipitation. Temperature trends were examined during peak winter and summer months.

The analysis clearly shows a growing tendency in low temperatures of the order of roughly 1C throughout the entire winter season at Leh (Figure 3) Similarly, the maximum temperature for the summer months has risen by about 0.7 degrees Celsius in the last 36 years (Fig.3) A one-degree increase in winter temperature has major consequences for glacial formation and water security in the Ladakh region in particular, and the Indus basin in general. Snowfall, which accounts for 70% of total precipitation, has fallen by roughly 4 mm over the time period Figure 4) while rainfall in the summer season, which accounts for 30% of total precipitation, has declined by about 3 mm (Figure 5).

Glaciers and snow melt water are critical to life's existence because they are the only source of water, whether for irrigating fields or for any other domestic purpose. Extremely low temperatures, combined with substantial snowfall during peak winters, are the most crucial variables for glacier extension, which was previously favourable. However, due to changing temperature and precipitation, small glaciers in the region have been retreating at a much faster rate than expected over the last 36 years, especially since the rising temperature trend is sharper in winter months and the declining precipitation trend is sharper in winter months. Winter precipitation is critical since it accounts for 70% of total precipitation (in the form of snowfall) over the course of the year.

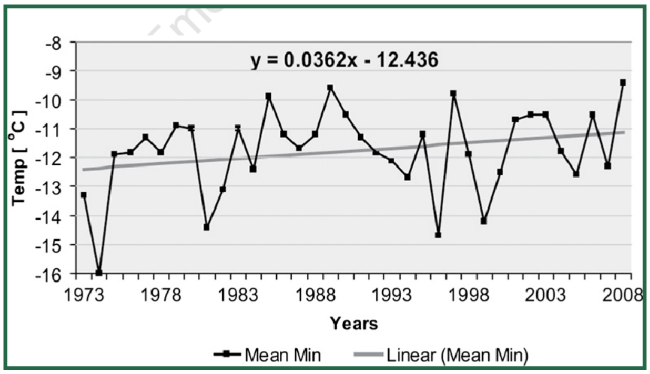

Fig. 3. Mean minimum temperature and trend, Leh–Ladakh (December 1973–2008)

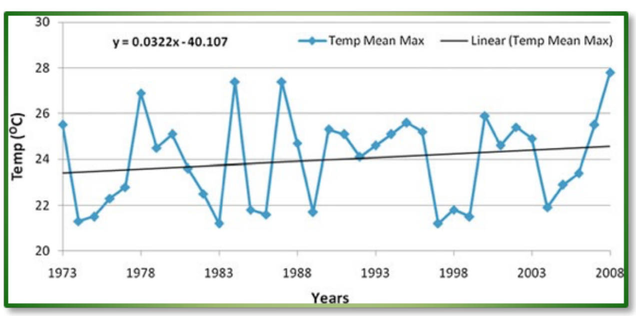

Fig. 4. Mean maximum temperature and trend, Leh–Ladakh (December 1973–2008)

Evidence of Climate change

The results of a survey of Leh households and 200 people over the age of 55 corroborated the meteorological data analysis. People were polled on their perceptions of temperature and precipitation change over their lifetimes, and the findings are

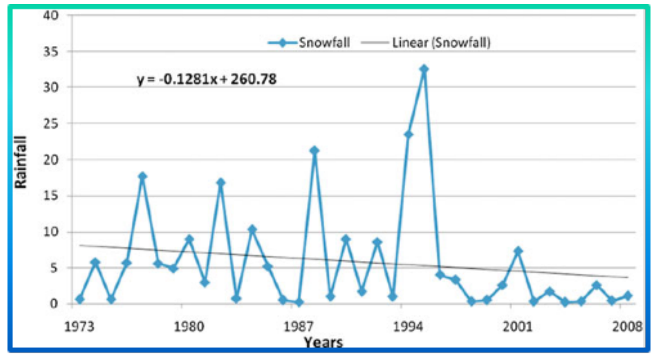

Fig. 5. Snowfall andtrend, Leh–Ladakh (December 1973–2008)

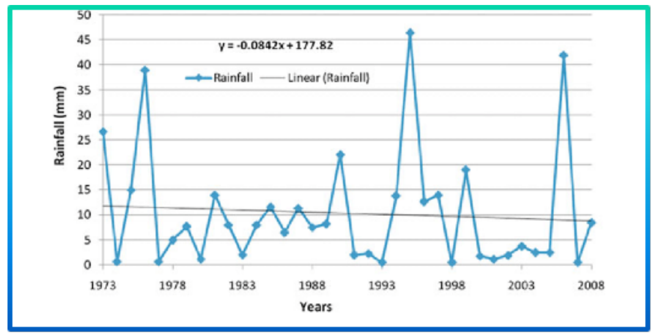

Fig. 6. Rainfall and trend, Leh–Ladakh (August1973–2008)

shown in Tables 1 and 2, respectively.

The majority of people interviewed in villages reported that winter temperatures have been rising and that the length of the cold season (winter) has been shortening. Similarly, the warm season, i.e., summer, is becoming longer; scorching temperatures are felt even in April. The climate data study for Leh confirmed this. People had a higher perception of less snowfall during the winter months (93%) than of little rainfall during the summer months (54%). The most obvious observation of climatic change by households throughout Leh district is the change in precipitation patterns – heavy and untimely rain, and less snowfall – along with increasing ambient temperatures that are leading to quicker snow melt, and thus a shorter season of flowing streams.

Changes in precipitation patterns - strong and untimely rain and less snowfall – as well as rising ambient temperatures are leading to faster snow melt and, as a result, a shorter season of flowing streams, as observed by households throughout Leh district. Even if population and per capita consumption pressures remain unchanged, less snowfall causes a slower recharge of ground water and springs, as well as a faster drying up of scarce water resources.

Water Availability

The majority of interviewees reported a decrease in water flow in glacier-fed streams and natural springs, according to the study. The rise in ambient temperature and heavy snow melt in Ladakh, as observed by households, can be confirmed by widely accepted anecdotal evidence that glaciers in Ladakh, such as Siachen, Khardong, and Stok – all well known for their strategic and scenic locations – have either receded or nearly disappeared in the last decade (1996-2006). People in Ladakh have traditionally not relied on the Indus for irrigation because of its shallow depth, poor water quality, and major difficulty extracting water from its depths without the use of polluting, inefficient motorized pumps. The altitude and atmosphere of Ladakh pose considerable mechanical challenges that are rarely experienced in any permanently inhabited region of the world.

Table 1. Perceptions of people regarding change in temperature

Perception	Percentage of households	
	Summer temperature	Winter temperature
Warmer	84	93
Colder	10	10
No change	1	2

Table 2. Perceptions of people regarding change in precipitation.

Perception	Percentage of households	
	Change in snowfall	Change in rainfall
More	3	86
Less	93	15
No change	1	2

Heavy snow melt is also affecting the livestock industry in the Leh area. Lower grazing grass yields have resulted from the removal of snow from neighbouring mountains. As a result, pastoral communities are now relocating more frequently than a decade ago from one region to another in search of grazing grounds. This has had an even bigger impact on the ability of the highlands to regenerate. Climate change has also resulted in an increase in the frequency and intensity of insect attacks. Warmer temperatures, according to the agricultural extension office and the Field Research Laboratory in Leh, have increased the incidence of such pest attacks.

In recent years, the effects of global climate change have become increasingly visible in the Ladakh region. Rainfall and snowfall patterns are shifting; small glaciers and permanent snow fields are melting, affecting water runoff in rivers and streams; and rising temperatures and humidity are fostering bug invasion and pest aggression. Climate change impacts are particularly severe in such extreme regions since they belong to one of the most vulnerable ecosystems and, on the other hand, people living in these areas frequently lack the ability to adapt to changing conditions. Temperature changes are already having an impact on the region's ecosystem and communities.

Some changes in bird migration patterns have been seen in communities and at Tsomoriri Lake (as reported by WWF and wildlife warden). Migratory birds, such as the Red-Shelldock, used to leave Ladakh before the hard winters of this frigid desert, but some have now remained here. Migratory species like as geese and Brahmani ducks have ceased migrating and can be observed in the area all year.

Similarly, breeding of the bar-headed goose and the black-necked crane has been pushed back in recent years, and migration routes of communities on Tsokar Lake (who raise the Changthangi goats from which the famous pashmina shawls are woven) have become more frequent as these pastoral communities migrate due to degrading pastures (WWF 2006). The Chadar trip is becoming shorter (January–February rather than December–March), and Tsokar Lake begins melting in early March rather than mid-April, making it difficult for pastoral nomads to cross with their livestock.

Observations

During the dry season, the only traditional supply of drinking water in Leh has been water from the Khardungla glaciers periodically replenished glacial streams and springs. Anecdotal information, together with measurements made by local officials, suggests that changes in Leh's climate have been detected, one of which is minimal accumulation of snowfall on the Khardungla glacier in the winter. Reduced snow cover means less recharge of groundwater and surface water, and thus less discharge in springs and streams that supply water to Leh.

Other effects of climate change reported in Leh include rising ambient temperatures, which cause faster melting of the snow-pack, reducing the number of days during which melt-water from snow is available.

Water scarcity is thought to be caused by both economic development (increased consumption) and climatic change in both towns (decreasing supply). Leh town has responded to water scarcity in a variety of ways, ranging from bottom-up innovation at the individual/household level to a somewhat more coordinated level of planning at the town division level. In the absence of coordinated efforts at the local, state, and national levels to assist Leh town in adapting to water scarcity, there has recently been some evidence of scattered responses to addressing water scarcity at the sub-local level, spearheaded by individual leaders, non-profit organization, and specific town departments in charge of municipal water supply.

The Issue

Ladakh is a high-altitude, cold-arid desert where people live at altitudes of more than 4,000 meters above sea level. The region has a population of roughly 2, 36,539 (2001 census), spread over an area of over 9.9 million hectares, and agriculture employs nearly 85 per cent of the workforce. Ladakh, located in the upper Himalayas' rain shadow zone, receives an annual average rainfall of 50 mm between May and July.

Subsistence farming on very small holdings (average land holdings 0.72 ha, with 80% of holdings smaller than one ha) with nominal animal husbandry and limited trading activity remains the mainstay of a large portion of the population, relying on hard work and scarce local natural resources to meet their daily needs.

In Ladakh, almost nothing grows naturally; everything must be farmed using irrigation techniques. The clever use of water is the key to farming in Ladakh. Ladakh has plenty of sunlight and fertile land, yet without water, it's a big arid desert. Almost 68 per cent of the whole area is above 5,000 meters above mean sea level and is unsuited for vegetation or human existence. Agricultural operations are limited to locations below 4,500 m in elevation, with a growing season of less than 6 months per year.

Ladakh does not allow for dry land farming. The entire 19,967 acres of cultivable area is reliant on reliable irrigation from glacier melt water flowing through long, stony, sandy, and meandering streams from the upper mountain reaches. Where there is a watercourse, there is habitation and greenery. Beyond that, there is no sign of vegetation or human settlement for miles, only endless tracts of arid plains until another patch of greenery and human habitation surrounds a small creek. Water from melted snow is what keeps life going, and most people live near glaciers and snow-melt water systems.

Ladakh's agricultural season begins in April, with the melting of snow in fields. The melting of snow is frequently delayed, prolonging the availability of water for irrigation and agricultural planting and, as a result, negatively reducing crop productivity. In the region, the summer season is brief and monoculture crops. Farmers must cultivate crops such as wheat, barley, peas, potatoes, Alfa-Alfa, and others at the appropriate period to allow them to ripen within the limited short summer season.

The agricultural season begins in April–May, whereas the process of snow and glacier melting at high altitudes occurs around the end of June. During the rest of the year, from August to April, relatively little water flows down the streams because the high mountain summits' temperatures do not allow snow to melt. This causes a delay in the seeding process, which reduces agricultural output. As a result, spring is the most critical season for farmers to begin seeding.

Water scarcity in Leh

In the last five decades, the management structure of water resources and the types of water use in Leh have evolved dramatically. Despite the fact that piped water supply is becoming more widely available, not all portions of town have access to it. In 2001-02, a total of 606 water connections were built in Leh, with 297 (49%) of these being private. Currently, roughly 375 private connections exist in Leh. 274 (73 per cent) of these private connections are owned by commercial users (i.e., hotels and guesthouses), implying that just a quarter of private connections are owned by residential users. This suggests that the majority of Leh families rely on PSPs for their daily water needs and 306 (51%) were public checkpoints (PSPs).

By 2009, the number of PSPs had increased to 389, with 150 of them operating during the winter. In Leh, there are currently about 375 private connections. 274 (73 per cent) of these private connections are owned by commercial users (i.e., hotels and guesthouses), implying that just a quarter of private connections are owned by residential users. This suggests that the majority of Leh families rely on PSPs for their daily water needs. People in Leh used to get water from springs until piped water was introduced (locally known as Chumiks).

Historically, Leh residents have demonstrated a strong tradition of thrift in their usage of water resources. Furthermore, regardless of class or location, traditional Ladakh toilets (dry composting toilets) were the standard throughout the town. However, with the availability of piped water and the growth of the tourism industry, a water-intensive sewage system with septic tanks, or in some cases, outfalls dumping waste-water into streams, is becoming more common in the town, putting additional strain on Leh's restricted water resources.

Locals have long dug bore wells in response to rising water demand and the drying up of common taps. "Almost every household, hotel, and guesthouse has its own private bore well, and there is no regulation governing it." All of the springs in Leh town have dried up, which we believe is due to ground water exploitation. The question will not be limited to the number of bore wells, but also to the amount of water extracted from the earth. It necessitates a thorough investigation.

Water consumption in Leh has been increasing due to fast urbanization, economic development, and population expansion. To bridge the supply-demand imbalance, PHE and private users (domestic and commercial) began tapping groundwater sources in the recent decade. Hotels, guesthouses, and some homes have erected private borehole wells to meet their water need as a result of the availability of bore-well technology.

Institutional Management of Water

The LAHDC is divided into divisions, one of which is the Public Health and Engineering Division (PHE), which is in charge of water management.

PHE is divided into three sub-divisions, with the Leh sub-division in charge of water supply in the town of Leh. The primary goal of this sub-division is to provide drinkable water to the people of Leh (National Informatics Centre, Leh District, and Ladakh).

Furthermore, PHE is in charge of sewage services as well, but prioritizes water delivery. Water tariffs in Leh are based on a fixed-tariff pricing structure. PHE provides water tankers in regions where piped water supply is not available. Furthermore, the lack of piped water connections in many parts of town has given rise to an informal water supply. In Leh, the average daily per capita water use in the home sector is 20 litres in the summer and 14 litres in the winter (Akhtar 2010). Households with private connections, on the other hand, are likely to consume significantly more water than those that rely on PSPs, tankers, or barrels.

Tourists' water consumption habits are found to be substantially different from those of local people, following the same logic of more supply driving greater demand. According to surveys, tourists use water-based flush toilets and consume 81 litres of water per day on average.

Sources of irrigation water

The possibilities of boring tube wells, canals, and even lift irrigation is limited in the hill region; such facilities are confined to low-lying areas. As a result, the little water channels known locally as Kuhls continue to be the most prevalent source of irrigation, accounting for 85.83 per cent of the total area under irrigation in hills.

Perennial streams provide water to several settlements in cold deserts, allowing them to irrigate their crops. Ground water fluctuates due to the vast differences in topography. The depth of the water in the valley is little, but it is deeper in the upper parts of Ladakh. Water depths at ITBP sites range from 1.3 m at Zorawar Fort to 43.36 m below ground level. The principal source of residential water supply is a spring. High altitude remote locations like Ladakh face various difficulties as a result of the cold desert region, yet the administration has created measures to improve runoff. Possible strategies include techniques for improving catchment runoff, a traditional structure used in Ladakh known as Zing, which are small tanks that collect melted glacier water), snow management, which is an important practise and source of irrigation water in cold arid regions, but declining glacier recharge by 21% has recently threatened a few villages where sowing and irrigation have been severely impacted.

The Defence Institute for High Altitude Research (DIHAR) has undertaken research on climate-resistant crop and vegetable types, as well as sustainable agriculture practices that use less water. DIHAR's study, for example, strongly suggests that drip irrigation and mulching are particularly effective water conservation measures in Leh's environment. Climate change research is important for urban Leh because the city has a large amount of urban agriculture. Indeed, PHE estimates that 20-30% of the drinking water given to residents of urban Leh is used for agricultural reasons.

Given the region's reliance on agriculture, it is apparent that DIHAR will play a critical role in making agriculture more sustainable in Ladakh. Furthermore, the growing local, military, and tourist population has created a demand for very water-intensive agricultural product that is not indigenous to Ladakh.

Although the local administration has been made aware of the importance of water scarcity issues, the government's major policy remains supply augmentation, with little emphasis on water conservation.

Water Management

The traditional ponds, reservoirs and khuls existing in many villages are in a dilapidated condition, which cannot store the melting water for long time. A lot of efforts were put up by different agencies to find out the possibilities to make these reservoir/ponds more spacious, efficient and strong. The khul and distributaries were also repaired to improve the efficiency, however, the main problem of making water available to farmers during the spring season still persist.

The need was, therefore, felt to develop a technique that will ensure the water availability to farmers during the critical stage of seed sowing period (April–May). The concept of artificial glaciers has been developed by Mr Norphel and his team based on ancient practices of harvesting melt-water. Artificial glaciers are large reservoirs that are created upstream of villages, which capture melt-water that would typically run off during fall and winter. This captured water is allowed to freeze during winter, and since it is collected at a lower altitude, it melts early enough to be used for irrigation in April. Water flowing in a natural stream is diverted via man-made channels onto slightly depressed ground at a lower elevation to form artificial glaciers. For four months, from November to March, water from the natural stream is diverted by a system of dams and gates. In the winter, this water pools on the land and freezes. When it begins to melt in April, it delivers water to a downstream settlement that is linked to the artificial glacier via another set of built channels. After March, the artificial channel is stopped by a gate, allowing the natural stream to resume its natural flow.

Typically, an artificial glacier can accumulate enough water to supply irrigation water to a land area of 250 acres, or the equivalent of 200 families. Funding for these projects in the past has been provided by the Central and State government. This water harvesting technique is still in an experimental stage, and will have to be tested in order to evaluate its viability as a reliable near-term solution to water scarcity.

Evidence of Climatic Changes and Shrinking Water Supply

Given that Leh receives minimal rainfall, the town has relied almost entirely on natural spring sources that carry snow-melt from the Khardungla Glacier, and more recently on groundwater to meet its water requirements. The Khardungla Glacier used to be a permanent glacier approximately 4-5 decades ago.

Since then, anecdotal evidence shows that this glacier has retreated, and essentially, the distance between the snout of the glacier and the town of Leh has increased.

Typically, glaciers melt faster at lower altitudes, but if they recede to higher altitudes, they take longer to melt. It is believed that this has led to lower discharge of water in springs and streams that are fed by the Khardungla Glacier. Changes in temperature and local precipitation have also been perceived by residents of Leh. Locals recall that until approximately 15-20 years ago, Leh used to experience a 'white winter' and would be covered with up to 6 inches of snow throughout the winter. Now, winters have become warmer, and snow does not accumulate for long within the town. It is estimated that Leh has experienced a temperature increase of approximately 1 Celsius on average.

An accurate approximation of the reduction in discharge of the water supply sources of Leh is not available. But it is estimated by engineers at PHE that the Juma Bagh spring and the T-Trench spring are serving at 25% and 50% capacity respectively, and the Shari spring has been reported to be 99% dry. Neighborhoods of Leh have shown a decrease in discharge as a result of a decline in the water table.

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The commercial sector has also perceived a decrease in the viability of water supply sources in Leh. For example, hotel owners have complained of pumping wells that had gone dry last year during the tourist season. This could indicate that the rate of extraction of water from these pumping wells is not sustainable and/or that the water table has been declining due to insufficient recharge from snow. In 2008, LAHDC hired a private consulting firm, Tetra Tech, to conduct a study on the augmentation and reorganization of water supply in Leh. In commissioning this study, the objective of LAHDC was to "ensure a sustainable and equitable water supply to Leh" (Tetra Tech 2009). Tetra Tech's proposal has not been made available to the public; this presents a risk of duplication of plans to address water scarcity in Leh. The most significant finding of this study is Tetra Tech's estimation of groundwater resources in the Leh region. According to the report, groundwater resources in the Leh region are abundant.

Community Based Adaptations and Mitigation

Adaptation is the processes through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. There are many options and opportunities to adapt.

These range from technological options to behaviour change at the individual level. The adaptation and mitigation measures taken by the community to combat the externalities of climate change were identified and assessed for broader implications The creation of artificial glaciers to combat the receding of natural glaciers, thereby, increasing water storage and its availability in summer and production of vegetables in the peak of winter, through improved solar greenhouses which mitigate the effects of CO_2 emissions, were identified as the major climate change adaptation and mitigation strategies. The creation of artificial glaciers to combat the receding of natural glaciers, thereby, increasing water storage and its availability in summer and production of vegetables in the peak of winter, through improved solar greenhouses which mitigate the effects of CO_2 emissions, were identified as the major climate change adaptation and mitigation strategies.

Artificial Glaciers

There are visible marks of climate change impact on the region. Over the years, winters are getting shorter, there is less snowfall, and whatever snow is there melts rapidly leaving the region before it can be used in the sowing season. The main purpose and need felt for creating of artificial glaciers were to make water available at the beginning of sowing time in the month of April when there is no water. The artificial glaciers are created at the top of the villages below the foothills on shady side. These glaciers are created with the objectives to ensure the availability of water during early spring season for cultivation; to enhance the crop productivity by making water available in adequate quantity and in time; to bring waste lands, uncultivated land under productive activities; to improve the cropping pattern of the farmers; to prevent the wastage of scarce water and to mobilize farmers participation in the management of artificial glacier formation and components of the irrigation system.

The artificial glacier has been operating in the area for the past so many years and is performing with great success. Farmers, in particular, are extreme happy with the positive results of the technology. Water from the artificial glacier melts much earlier in the year than the natural glacier. The process is able to take place in spring, whereas, with the natural glacier water melting, cultivation would take place 20–30 days later, thereby, adversely affecting the crop yield.

The wastage of water from the winter can later be used for irrigation. In this region, only one crop can be taken, after which the water goes to waste. With an adequate quantity of water available at this earlier stage, more areas can benefit from the production of food crops, vegetables, fodder crops, trees, willows, poplars, etc. There is environmental and social impact of this technology too in the positive direction. It has helped to increase the ground water recharging in the area as the existing springs in the village produce more water. The artificial glacier can be used despite low snowfall, as water produced at the spring can be frozen at lower altitudes and converted to ice within the vicinity of the village. With the artificial glacier being so near to the villages, people save time accessing water and there is a decrease in loss of water due to seepage. The summer season now gets extended since water is available from month of April which has enabled farmers to grow additional crops like potatoes and green peas in addition to other vegetables, which fetch them good income.

There is increase in availability of labour man-days as farmers now get relatively more employment on their fields and has, thereby, checked the emigration of people from these villages. Furthermore, due to adequate and timely availability of water, it has reduced the water sharing disputes among the farmers and has brought social cohesion in the project villages.

Recommendations

Relevance of Artificial Glaciers with Climate Change

In the aftermath of climate change, the construction of artificial glaciers is a high-altitude water conservation technique. As glaciers recede and winters get shorter and warmer and snowfall disappears quickly the time window for utilization of water for agricultural irrigation during the sowing season gets shortened making it a challenge for farmers to locate water when it is needed. Natural glaciers are way up in the mountains and melt slowly in summer reaching the villages in June, whereas, artificial glaciers start melting in spring right when the first irrigation requirement is called 'Thachus' (in Ladakhi which means 'germinating water') is most needed.

Thus, the development of artificial glaciers is a method of harvesting glacial melt-water for farmers' irrigation requirements, which would otherwise go to waste and be of little use. Artificial glaciers need to be created in similar geo-climatic regions, such as Lahaul and Spiti in Himachal Pradesh, India; the HinduKush Himalayan range of Pakistan and Afghanistan; and some central Asian countries like Kazakhstan and Kyrgyzstan. In areas with elevations ranging from 4,666 to 5,333 m, temperatures as low as -15° to -20°C during peak winters, and longer winter periods of 4–5 months to ensure glacier expansion and formation, the technology can be replicated.

Low Carbon Solar Greenhouse Vegetable Production

Small-scale agriculture, with an average holding size of 0.72 ha, combined with monoculture and a restricted growing season limits the region's possibilities for family food security, which is often shut off from the rest of the country. During the summer, the majority of fresh vegetables are trucked in from the Indian plains. However, from November to May, the two main access highways (from Manali and Srinagar) are closed, and the capital city, Leh, is the only place to acquire fresh supplies, which are delivered by air. Mountain people are particularly vulnerable to food shortages and chronic malnutrition because of a number of reasons, including their isolation, the harshness of the climate to which they are exposed, and the difficulty of growing nutritious foods on inhospitable terrain. Most families do not have access to fresh vegetables during this period, either because they reside in rural places or because the costs are prohibitively expensive, preventing them from eating a balanced and nutritious diet. Food security and nutrition are critical components of long-term mountain development.

The agricultural department of Leh's implementation of a solar greenhouse project in 2020 is based on a passive solar concept: solar gain, heat storage, heat release, insulation, and ventilation, and provides significant experience as to the potential of aiding small-scale farmers living in cold dry locations to enhance their livelihood. The greenhouses, which are totally heated by sunlight to keep the internal temperature high enough to produce vegetables even when the outside temperature drops to –25°C, aid in the development of seasonal and off-seasonal vegetables. As a result, it ensures low-carbon vegetable production, which replaces imports that were previously carried by truck during the summer or by air during the winter. As a result, the project helps to reduce greenhouse gas.

Monitoring Systems for Snow-Cover, Surface Water, Groundwater, and Climate Parameters

In Leh, there is a scarcity of long-term data on snow cover, surface water, and groundwater resources, as well as other climate variables including rainfall and temperature.

In terms of snow cover, previous research have shown that technology like remote sensing allow for regular and repeated snow cover monitoring. This sort of monitoring, however, should be done at a regional level.

The findings on glaciers in the Khardungla region could then be shared with municipalities so that they can monitor local climatic changes that affect their water supply. According to current literature on remote glacial monitoring, monitoring systems should ideally incorporate both ground-based and satellite-based monitoring in order to provide the most accurate data. However, funding for this technique may be attainable under India's present NAPCC, which includes provisions to establish "if and to what degree Himalayan glaciers are in recession."

Finally, Leh town's regulatory monitoring systems, notably for groundwater resources, need to be improved. The future viability of groundwater resources cannot be determined in the absence of monitoring systems that regulate groundwater extraction since there is no way to verify if groundwater is being recharged at about the same rate as extraction.

Regional Climate Models

The Himalayas have not been effectively studied and represented in global climate models until now owing to a number of political & logistical issues. To be able to predict future climate change consequences in the Himalayas, regional climate models (RCMs) with a greater resolution than global models must be specifically developed for the Himalayas' most vulnerable regions. Also, the Himalayan glaciers feed most of the rivers of the subcontinent and a study on this will yield valuable data and patterns on water usage as well.

Ladakh is an area where the effects of climate change are expected to be particularly noticeable. Climate modelling could be an important tool in this context to assist predict and understand any changes that may occur, as well as to aid in the development of adaptation methods.

Storage Systems

Leh lacks the necessary storage capacity to mitigate inter-seasonal fluctuation in water supplies. The IPCC considers the development of water storage to be a major adaptation measure for climate change consequences. To expand storage capacity in Leh town, a combination of natural and manmade methods could be used, depending on geophysical circumstances. Rainwater could be collected in ponds and tanks, for example. Artificial glaciers and ponds have been built in peri-urban and rural Ladakh under the leadership of community groups such as LNP and LEHO to lessen inter-seasonal unpredictability in water availability.

Eco tourism

Hotels in Leh should make an effort to deliver water conservation messages to encourage guests to use less water.

Furthermore, because the tourist business is mainly reliant on nature tourism and outdoor activities like trekking and bicycling, efforts may be made to incorporate environmental education into tour packages offered by travel firms. For example, travel agencies could publish colourful brochures with information about the glacial sources of water in Leh, the impacts of climate change on these sources, and their translational effects on water supply, and guided tours/treks in the Khardungla region could emphasize the importance of these glacial systems for the survival of downstream urban societies to provide a meaningful, educational experience for tourists.

Results and Discussion

Gaps between Science and Policy

It is apparent from the developments that Leh lacks any solid, long-term specific scientific study on climate change and hydrological implications to mar informed decisions concerning the future of water supply. There is virtually little quantitative data to back up anecdotal information regarding the Khardungla Glacier's shrinking snow-pack. In general, the research on glacial systems reveals significant gaps in climate change science and its effects on Himalayan glacial and hydrological systems.

Because current geographical resolution of models is insufficient to fully describe and reliably anticipate climatic reactions, only a few climate models have attempted to simulate implications of climate change in the Himalayas. This lack of specific research, combined with gaps in the data collected at the local level by Leh, makes formulating science-based policy in cities like Leh extremely challenging.

Lack of Meteorological Data & Technological Resources for Monitoring

Leh lacks reliable, long-term meteorological data (spatial, qualitative, or quantitative) on natural parameters such as temperature, precipitation (rainfall and snowfall), stream discharge, and groundwater resources, all of which can be used to analyse and infer changes in climatic patterns or estimate future trends.

Leh has historically relied on streams or springs that emerge spontaneously from the subsurface to meet its water needs. These sources are derived from the Khardungla Glacier's snowmelt. However, some of these traditional sources (especially streams) have become unviable in recent years, which is linked to the Khardungla region's declining snowpack.Because there are no monitoring systems in Leh that collect quantitative data on variations in the average volume of snow on the Khardungla Glacier, anecdotal evidence and local informal knowledge are used to gain a sense of how climate changes are influencing Leh's water sources.

Gaps in Data

The information on water treatment is another example of the data gaps in PHE's database. There isn't enough information to determine what proportion of water is treated before it is consumed. However, it is widely assumed that the water sources in Leh are unpolluted and not at risk of major contamination. For example, hotels that draw groundwater using borewells do not treat it before distributing it.

Lack of storage reservoirs

Leh is unable to store more than a day's water supply and has no storage capacity to guard the town against unforeseen drought-like circumstances. The reservoirs' combined storage capacity is hardly enough to hold a day's worth of Leh water, which is 3.52 million litres. Furthermore, the reservoirs are not evenly spread around the town, resulting in some areas of the town lacking appropriate storage capacity.

The Availability of Data

To begin with, Ladakh's historical, political, and economic backdrop has an impact on the quantity, quality, and accessibility of scientific research. Because there is no governmental meteorological station in Ladakh, the readings provided by the Indian Air Force appear to be the only scientific data available. The data is, however, highly guarded by the Indian Armed Forces, due to the region's militarily sensitive character.

Concluding Remarks & Policy Suggestions

Water connects the climate system to our human biosphere, and it should be at the centre of the conversation about how to best address the climate catastrophe in local context. Although climate change has such a broad impact on water, much of climate change adaptation transfers into water adaptation.

Arid and semiarid regions like Ladakh are expected to see considerable temperature rises and less precipitation in general. In these situations, capturing and storing water so that it may be used for food production becomes critical. The need of the hour is to scale up solutions like artificial glacier technology and solar greenhouse low carbon vegetable production in ecologically severe and fragile environments to mitigate climate change's impact on the local populace.

To be able to understand any large climate-related problem on a local scale, meteorological data is of paramount importance, only a thorough study, analysis and interpretation of it can lead to meaningful outcomes and within social and ecological systems, it is critical to developing local knowledge, innovations, and practices, as well as the functioning of institutions that are critical to adaptation.

To promote the formulation and implementation of sound policies, sound science should be combined with credible, relevant, and genuine knowledge. Researchers and development organizations should continue to improve adaptable technologies, and donor agencies should provide financing to help them be used on a larger scale.

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