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Dynamics of urban water supply management of two Himalayan towns in India

Neha Bharti[a,*], Neha Khandekar[a], Prateek Sengupta[b], Suruchi Bhadwal[a] and Ishaan Kochhar[c]

[a]*The Energy and Resources Institute (TERI), Delhi, India*

**Corresponding author. E-mail: neha.bharti@teri.res.in*

[b]*Centre for Ecology Development and Research (CEDAR), Dehradun, India*

[c]*International Centre for Integrated Mountain Development (ICIMOD), Patan, Nepal*

Abstract

Many towns in the Indian Himalayan Region (IHR) are experiencing permanent water crises due to increasing population pressure, urbanization, and poor management of existing water sources. This paper focuses on two towns – Mussoorie and Devprayag in the western IHR – to understand various aspects of the growing water scarcity and urban water management. In the current scenario of a changing climate, natural springs, their main water resource, are drying up. Mussoorie experiences an acute shortage of water in summer, precisely when the town hosts numerous tourists. In Devprayag, religious tourism and in-migration from rural areas contribute to rising demand. The reduced discharge in nearby streams has widened the demand–supply gap. An integrated management of water sources is crucial to solving water problems in Mussoorie and Devprayag. In both towns, little effort has been made towards recharging existing water sources. Detailed planning of the water supply system while being mindful of the floating population, a proper sewage and storm water management system, and rainwater harvesting schemes, are absent. There is an urgent need to adopt a comprehensive approach to solving urban water issues, covering aspects of demand, supply and water resources management in these hill towns for adaptive water management.

Keywords: Coping strategies; Indian Himalayan Region; Springs; Urban water management; Water demand; Water supply

Introduction

The Hindu Kush Himalaya (HKH) region is wide, encompassing more than 4.3 million km^2, including high mountain areas in Afghanistan and Pakistan in the west, India, China and Nepal in the centre,

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and Bangladesh, Bhutan and Myanmar in the east (Schmid *et al*., 2015). The Himalayan range in India, being home to ten large Asian river systems, provides water to more than a 1.9 billion people. These rivers provide fresh water for drinking, domestic uses, industry, irrigation and power generation (Mukherji *et al*., 2015; ICIMOD, 2018).

The Ganges is a transboundary river, with its headwaters originating in these mountains. The Upper Ganges Basin, in which our sites of study are situated, is located in the northern Himalaya, and encompasses an area of over 87,000 km^2 (Figure 1), with a wide variation in elevation and climate. Its elevation ranges from about 7,500 metres above sea level (masl) to around 100 masl (Bharati & Jayakody, 2010; Bharati *et al*., 2011). Average annual rainfall ranges from 550 to 2,500 millimetres (mm), with most of the rainfall falling during the southwest monsoon (Bhadwal *et al*., 2017).

With a glacier coverage of 60,000 km^2 (Bajracharya & Shrestha, 2011), the HKH region is referred to as the 'Water Tower of Asia' as it provides around 86,000,000 cubic metres (m^3) of water annually, feeding many of its major rivers (Rao *et al*., n.d.). However, rapid warming has resulted in the shrinking of snow, ice, glaciers and permafrost in the region (You *et al*., 2017). Scientific evidence indicates that glaciers in the HKH region have been receding, similar to glaciers in other parts of the world (National Research Council, 2012; Bajracharya *et al*., 2015). As well, the decline in snowfall and erratic rainfall

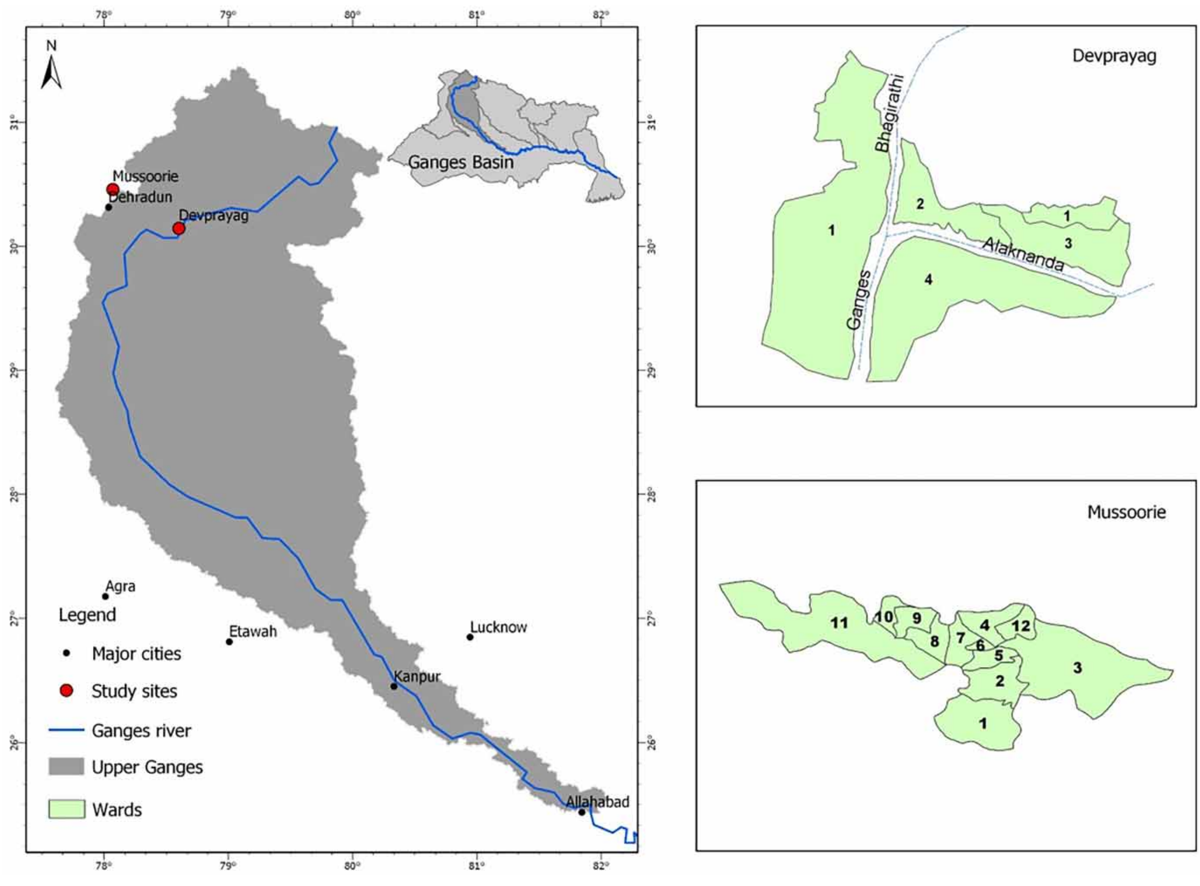

Fig. 1. Upper Ganges Basin (left) and study sites with the wards in Devprayag and Mussoorie (right).

patterns has had an impact. The Ganges Basin draws 9%–10% of its waters from glacial melt, the rest of it being largely fed by rainfall (Khan *et al*., 2017).

Hence, a combination of factors has adversely affected water supplies. There are also issues of springs drying up in many parts of the mountains due to the lack of adequate recharge owing to changing rainfall pattern and catchment degradation. Pioneering work in these regards was carried out by Valdiya & Bartarya (1989), identifying deforestation of hill slopes as one of the primary causes. The drying up of springs will affect the flow of rivers in the region and also most of the mountain communities who depend on springs (locally known as *naula* or *dhara*) for their drinking and domestic water needs.

Conversely, an increasing demand for water, with a rising population, has added to the stress on water resources in these river systems. The current population of the HKH region is about 1.9 billion (Sharma *et al*., 2019). In recent years, the number of cities and towns has also grown manifold, thus increasing the demand for water. Most of the increase in population is concentrated in the cities and towns in the mountain states, largely owing to the migration of people from rural and semi-urban areas seeking better access to basic facilities, including employment and education. Urbanization, therefore, presents huge challenges for meeting the water requirements of a continuously growing population.

Small towns and cities in this region also have a continuous, floating population, consisting of tourists travelling and staying in these towns for short periods, because of the region's cultural and spiritual significance. They are not generally considered part of the official census count. According to the Uttarakhand Annual Plan 2013–2014, the floating population observed in Uttarakhand during peak months ranges between 0.3 and 0.35 million. This further increases the seasonal demand for water (Government of Uttarakhand, 2014).

A physical scarcity of water is already being observed in many parts, especially the mid-hill regions (Bhadwal *et al*., 2017). According to Government of India norms, the per capita water availability for urban areas ought to be 135–150 litres per capita per day (lpcd), but the poor living in slum areas near the urban centres receive only 72–74 lpcd (Bose & Srivastava, 2017; NIH, n.d.). Climate change is likely to add further pressure on the water resources in these regions.

With this overview in mind, this paper seeks to study the multiple factors influencing water supply and demand in Himalayan cities and towns in Uttarakhand, with the objective of suggesting possible measures to decrease the vulnerabilities of communities to water stress. We present the empirical findings from a study undertaken to investigate water access and availability, and lacunae in current water management approaches in Mussoorie and Devprayag, in the state of Uttarakhand, India (Figure 1). Both these towns vary in size considerably and have floating populations, for different reasons. We investigate the various factors compounding the situation, which increase the challenges of communities living in this region. We have attempted to document the policy, regulatory and institutional support governing water resources and unearth gaps therein. Alternative sources and coping mechanisms have been identified through field-based discussions, to better understand the fallback options that communities facing complex constraints have in dealing with resource scarcity.

Study area

Mussoorie, a medium-sized town, lies in the foothills of the Garhwal Himalayan range and is part of Dehradun district in Uttarakhand. Devprayag is a small-sized town in Tehri district. It is one of the most important pilgrimage centres in northern India for devout Hindus. The rivers Bhagirathi and Alaknanda merge at Devprayag to form the Ganges. Mussoorie has an average elevation of 2,006 metres (m) and Devprayag 830 m. Devprayag is 8.75 km^2 in area and Mussoorie 67.6 km^2 (Ramachandran & Ramachandran, 2001; Asian Development Bank, 2014). Mussoorie currently has a municipal board divided into 12 wards, whereas Devprayag has four wards, also governed by a municipal board (Nagar Palika Parishad) (Figure 1).

Mussoorie has experienced a tremendous population expansion and unregulated growth (Hewitt & Mehta, 2012). Its population grew from 18,241 in 1981 to 30,118 in 2011. In contrast, Devprayag's population has remained almost the same, rising very slightly from 2,769 in 2001 to 2,868 in 2011 (Ministry of Home Affairs, 2001, 2011).

Mussoorie's demographic spread is diverse. It has some densely packed wards, with buildings up to four floors; it also has high-rise, eight-storey apartments, in wards 8, 9 and 10. Slum areas and residential quarters in many wards are often found with common water and toilet facilities. Devprayag is sited at a height of 30 m above the water level. It is divided into three areas, separated from each other by the holy rivers. These areas are connected with each other only by the means of two suspension bridges, over which only pedestrians can pass. The houses are generally two-storeyed, and the old houses are built of large stones (AHEC, 2011).

It being one of the fastest growing hill stations in northern India, with a high tourist influx in summer and attracting around half a million tourists annually, were the pivotal reasons for having selected Mussoorie as one of the two sites of research for this study. Conversely, Devprayag is one of the most important pilgrimage centres in India, with a tourist influx mainly concentrated during the 'Char Dham Yatra' season. Additionally, the increase in in-migration from rural areas nearby is causing a very gradual rise in Devprayag's population, making it an interesting case to study. It was also unfortunately one of the worst affected areas during the Uttarakhand flood disaster of 2013, which, among other impacts, badly affected the water infrastructure.

Methodology used

The study used a mixed method approach for an in-depth understanding of the emerging water situation and adaptive mechanisms to address water-related challenges in the context of water consumption for drinking and domestic purposes. It combines quantitative data from household surveys, qualitative evidence from focus group discussions within the wards, and interviews with key informants in municipal offices, the relevant government departments, hotels/restaurants, clinics/hospitals and NGOs, among others.

The sample size for the household survey was 350 households, divided across the two towns. The sample size in each town was determined using the unitary method, in proportion to the number of households in both towns. The total households in Mussoorie and Devprayag are 6,445 and 739, respectively. The sample size for Mussoorie was calculated at 314 households in 11 wards. For Devprayag, it was 36 households in four wards.

A structured household-level questionnaire was used to survey the sample households in the two towns. The survey was conducted over January–March 2017. Households within wards were selected to represent different, relevant contexts – caste background, with or without water supply connection, elevation amplitude, whether the house was rented or owned, and differential access to primary and alternative sources of water. The quantitative data were collected using Akvo Flow tool on a smartphone and a simple analysis was conducted on the survey data exported from the tool.

Household socioeconomic profile

Most respondents are between 30 and 50 years old, with educational levels up to higher secondary. Most families in Devprayag have a stated average monthly household income below INR 30,000. In Mussoorie, it is between INR 15,000 and 50,000 for 72% of the respondent families. The average family size ranges between three (Devprayag) and five (Mussoorie) members.

Most of the respondents live in houses they own – 92% in Devprayag, 69% in Mussoorie, most in *pukka* (cemented) homes. A large proportion of respondents in both towns live in 1–2 room-set houses. Importantly, 89% in Devprayag and 72% in Mussoorie have access to private toilets. A significant proportion of the sample population in both towns has migrated there, either from nearby villages, or from neighbouring countries and regions such as Nepal and Tibet, and have been settled there for 5–10 years. Around 20–40% of the respondents in both towns are permanent residents (Figures 2 and 3).

Water sources and supply

Primary water sources:[1] *Uses, frequency, duration, location and expenditure*

All households in both Mussoorie and Devprayag rely heavily on municipal water supply for various domestic purposes like drinking, cooking, washing and bathing. Around 8% of the households in Devprayag which do not have private municipal water connections collect water from nearby public stand posts for drinking or other domestic purposes. In Mussoorie, 90% of the respondent households have access to a municipal supply. Of these, only 62% have municipal taps inside their homes; the rest 38% (which do not have the infrastructure to facilitate the supply of water) are dependent on water from public taps/stand posts for drinking and other domestic purposes[2]. The remaining 10% of sampled households in Mussoorie which do not have private water connections or access to public taps/stand posts access the closest spring source available and so that becomes the primary source for them (Table 1).

In both the towns, municipal water is supplied every day to the private water connections. Even for the public taps, almost every household in both towns said they received the water daily. Private connections in Devprayag received municipal water supply for a longer duration than Mussoorie. Households in Devprayag used to receive only 1 hour of supply per day until December 2016, but have been getting water an additional hour per day since then. Every surveyed household in Devprayag mentioned receiving more than 2 hours of water supply daily, whereas in Mussoorie, a major proportion of households (71%) received only 1 hour a day of private municipal supply. Many public stand posts in Mussoorie regularly supply around 2 hours of water daily but the number of users for each tap is absurdly high (Table 2).

Private water connections in both the towns are unmetered. Users pay a tariff decided by Jal Sansthan – the official government body dealing with drinking water supply and management in Uttarakhand –

[1] A primary water source is one that the households primarily have access to, and rely on, for fulfilling their domestic needs. It includes private water connections and public taps/stand posts, both supplied by the municipal authorities.

[2] These households do not have private water connections due to either of two reasons: (1) the houses are *kuchcha* (non-cemented) and do not have the necessary infrastructure to accommodate a water supply line; (2) they are located in those parts of town where there is an absence of piped water supply.

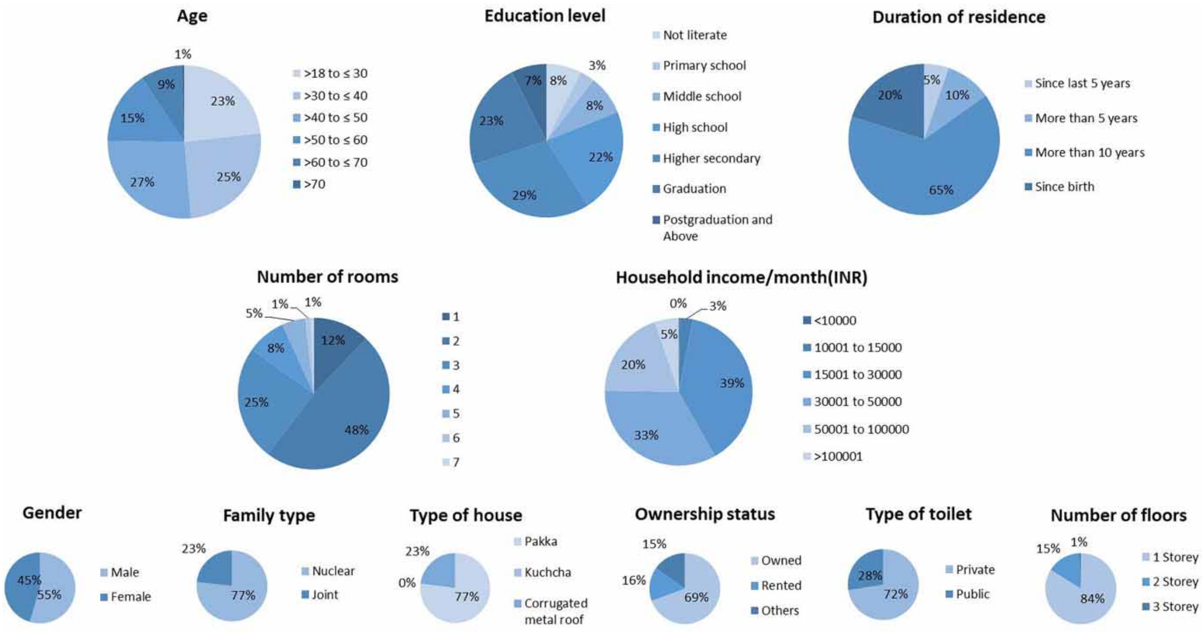

Fig. 2. Household-level information – Mussoorie.

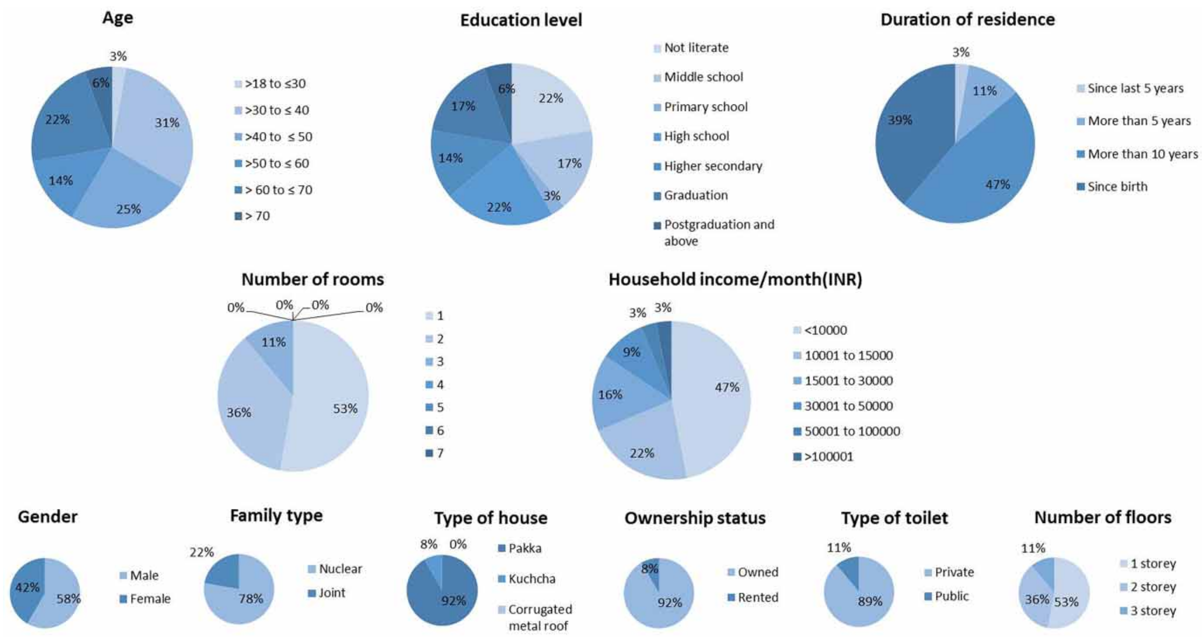

Fig. 3. Household-level information – Devprayag.

Table 1. Primary sources of water.

Primary source for domestic uses	Number of households (%)					
	Mussoorie			Devprayag		
	Public taps/stand posts	Private taps	Total	Public taps/stand posts	Private taps	Total
Municipal supply	38	62	90	8	92	100
Springs	10			NA		

Table 2. Water access: Frequency, duration and tariffs (% households).

Water access	Frequency		Duration/day		Monthly tariffs (INR)	
	Mussoorie	Devprayag	Mussoorie	Devprayag	Mussoorie	Devprayag
Private taps	Daily (100)	Daily (100)	1 hr (71) 2 hrs (27) >2 hrs (2)	> 2 hrs (100)	Up to 300 (89) 301–600 (4) >600 (7)	301–600 (100)
Public taps	Daily (97)	Daily (100)	Up to 1 hr (28) Up to 2 hrs (67) >2 hrs (6)	> 2 hrs (100)	Free	Free

based on a flat rate that takes into account two factors – the size of the property and its circle rate, and the height (or distance) to which the water is pumped. Most holders with private connections in both towns pay between INR 300 and 600 a month. A few households in Mussoorie, mainly those in high-rise apartments, pay a tariff of more than INR 600 per month (Table 2).

Piped water supply infrastructure

In both the towns, springs are the source of the piped water supply system. In Mussoorie, the municipality taps 20 spring sources to generate 9 million litres per day (MLD) of water, transported by gravity and pumping systems. There is a 98 km-wide network of distribution pipelines, with 4,065 domestic and 1,206 commercial tap connections, covering approximately 90% of Mussoorie's area. Conversely, Devprayag, being a small town, has only two spring fed streams (called *gadheras* locally), Randigad (13 km away) and Diwanigad (7 km away), supplying water to the town by the gravity system (Tables 3 and 4).

The total volume of water currently supplied in Mussoorie is 9.1 MLD against the total local demand of 6.9 MLD (Table 3). However, in reality, the town is always bursting with tourists and thus the water requirement exceeds the water availability. For example, in the summer of 2014, Mussoorie's total demand, at 14.4 MLD, was almost twice that of its supply (7.67 MLD) at the time (Ramola, 2014).

Despite geographical constraints in Mussoorie, Jal Sansthan has attempted, through the pipeline system, to reach most of the settlements in the town requiring water. There is still however a huge gap in the number of households having private connections (62%) and households not having access to the water supply system and depending either on public taps or directly accessing springs (38%). In Devprayag, the total water supply before 2014 was 0.39 MLD, far less than the demand of 0.7 MLD. What is more, the Uttarakhand floods of 2013 severely damaged the town's water supply

Table 3. Municipal supply of water to Mussoorie.

S. no.			Name of source	Volume of water supplied (MLD)	Type of source
A.	**Pumping schemes**				
1.	Murray Pumping Scheme	1	Khanalty	0.648	Spring
		2	Undercliff	0.155	Spring
		3	Bansi	0.288	Spring
		4	Kandighat Upper	0.288	Brooklet
		5	Kandighat Lower	0.691	Brooklet
		6	Rikhauli Gad	0.360	Brooklet
		7	Kandighat Stream	0.360	Brooklet
2.	Mackinnon Pumping Scheme	8	Newby	0.115	Spring
		9	John Mackinnon	0.216	Spring
		10	Chalmer Khud	0.115	Spring
3.	Bhilaru Pumping Scheme	11	Bhilaru	1.296	Spring
4.	Jincy Pumping Scheme	12	Jincy	2.419	Spring
5.	Kolti Pumping Scheme	13	Koltikhala	0.864	Brooklet
6.	Dhobighat Pumping Scheme	14	Dhobighat	0.763	Spring
B.	**Gravity schemes**				
1.		15	Company Khud	0.086	Spring
2.		16	Brookland	0.129	Spring
3.		17	Nalapani	0.036	Spring
4.		18	Pargakhala	0.158	Spring
5.		19	Douglas Dale	0.129	Spring
6.		20	Sentipani	0.072	Spring
	Total			9.188	

Source: Jal Sansthan (2017).

Table 4. Municipal supply of water to Devprayag.

S. no.	Name of source	Volume of water supplied (MLD)	Type of source
A.	Gravity schemes		
1	Old Randigad	0.21	Stream
2	Old Diwanigad	0.18	Stream
3	New Randigad	0.50	Stream
4	New Diwanigad	0.36	Stream
	Total	1.25	

Source: Jal Sansthan (2017).

system, adversely affecting the already stressed supply. In addition, the scheme was quite old and facing production problems due to high turbidity in the monsoons. To address these issues, in 2014, Jal Sansthan, with support from the Asian Development Bank (ADB), started work to reconstruct and rehabilitate the town's damaged water supply system. It also had the objective of augmenting the water supply components by adding new infrastructure in order to meet the prospective demand of the town for another ten years. The new distribution line started in December 2016 from the above two sources, supplementing the existing supply system with an additional 0.86 MLD of water. Thus, according to Jal Sansthan, the current volume of water supplied is around 1.25 MLD, almost double that of local demand, to meet the needs arising out of in-migration from surrounding rural areas.

Alternative water sources

If the primary source of water is not available, the alternative sources to rely on in the basin, mentioned by the respondents, are Ganges River water, springs, public stand posts (also supplied by municipal water) and water sourced from public and private water tankers.

In Mussoorie, the public stand post is the most preferred alternative option; 43% of the surveyed households use it for all purposes when regular private water supply is disrupted. Private water tankers and direct access to springs are next, used by 17% and 11% of the households, respectively. Many households using public stand posts, springs and water tankers also curtail their consumption due to limited water availability (Figure 4).

Water shortages are highest during May–July due to high tourist demand at that time of year combined with it being the lean discharge period of water sources. Spring water is used by 29% of the households surveyed in Mussoorie. This includes people's direct access to springs and municipal water sourced from springs, such as stand posts and municipal water tanks. However, as many as 91% of the households use it only during a water crisis (when the primary source of water is not available). Around 73% of Mussoorie's spring users access springs only in summer and the pre-monsoon period, and the remainder throughout the year. Almost all users use water supplied by tankers only during a crisis, most of it during the summer and pre-monsoon periods (Table 5). Private water tankers are usually called by a group of households (20–30 or more) in the same locality. The water is collected in large containers and carried back home. The price of the water ranges from INR 0.40–1.5 per litre, depending on the distance travelled by the tanker from the source to the locality, and the quality of the water.

In Devprayag, 44% of the households collect water from the Ganges River for all purposes when municipal water is not available. This usually happens during the monsoons, when the supply line gets cut off due to landslides or the destabilization of slopes. Those who have other options do not drink it due to quality concerns, but use river water only for washing and bathing. Around 17% of households close to spring sources use it for drinking and for other uses switch to river water (Figure 5). Of those who access springs, most use them only during periods of crisis during the monsoon, when there is a regular interruption in the supply due to the breakage of pipelines (Table 5).

There are no private water tankers that supply water to Devprayag, only municipal tankers which supply water during water shortages or when the pipelines are cut off. The municipality does not charge anything

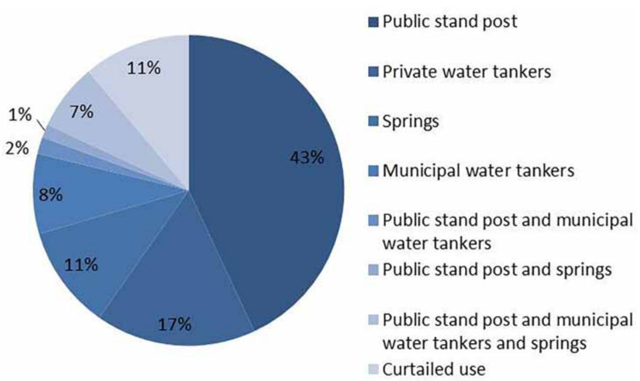

Fig. 4. Alternative water sources for Mussoorie.

Table 5. Alternative sources of water: Frequency, season used and costs.

Alternative source	Users (%)		Frequency of use (%)		Season used (%)		Cost/litre (INR)	
	Mussoorie	Devprayag	Mussoorie	Devprayag	Mussoorie	Devprayag	Mussoorie	Devprayag
Spring	29	19	Very often (9)	Very often (14)	Throughout the year (27)	Throughout the year (14)	NA	NA
			Only during crisis (91)	Only during crisis (86)	Summer and pre-monsoon (73)	Monsoon (86)		
Water tanker	31	22	Only during crisis (100)	Only during crisis (100)	Summer and pre-monsoon (100)	Summer and pre-monsoon (100)	0.4–1.5 INR	NA

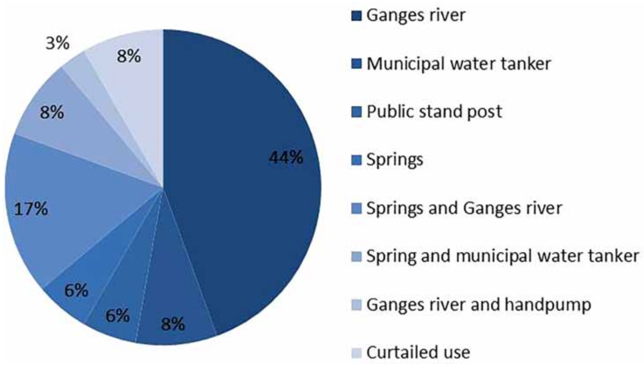

Fig. 5. Alternative water sources for Devprayag.

for the water supplied in crisis through tankers. Yet, only 26% of the households use water tankers as an alternative in Devprayag, as the town is situated on a hill slope and the tanker cannot travel easily to many houses because of the absence of a drivable road. It is difficult for people in households located down the hill to go up and collect water from the tanker. It is also easier for them to access the river.

Perceptions regarding water quality and seasonal variance

Overall, the water quality of all sources is perceived to be acceptable in both towns, except for the water provided by water tankers and river water. About 33% of users surveyed in Devprayag reported that tanker water was not clear and was of unacceptable taste. In Mussoorie, although its odour and taste were deemed acceptable, 10% of the respondents using water from tankers found it not to be clear. In Devprayag, some of the respondents found the river water neither to be clear nor taste right. A few municipal water users reported odour issues. They attributed this to the water being sourced from one of the springs having a village upstream. The spring upstream is used by livestock, for drinking and washing, which might be the cause of the perceived 'foul smell' by the respondents in Devprayag. The water quality of spring sources, in general, is perceived to be most satisfactory by users in both towns (Figures 6 and 7).

However, the quality of water from all the sources is said, in both towns, to vary seasonally. It dips most during the monsoons. For instance, most users in these towns say that the quality of municipal water – which is the major source for drinking – is merely average in Mussoorie and poor in Devprayag during the monsoon. Respondents in Devprayag even find the quality of the Ganges water poor and not potable during the monsoon, but the quality of spring water is good for half of the respondents even then. However, in Mussoorie, a majority of the respondents questioned the quality of tanker water and even springs during the monsoon.

The reasons cited for the fluctuating quality and supply of water included the supply pipes getting damaged during the monsoon by debris from landslides or slope destabilization. Users situated some distance from the pumping stations have mentioned that during the monsoon, rainwater gets mixed with their supply due to problems in the pipe network. Also, tanks and reservoirs at the source receive a great deal of debris during the monsoon, which enters the main lines and contaminates the supply. Spring sources are also contaminated, especially during the monsoon season, due to human settlements in the catchment area. Since tankers are filled directly from these sources, the water provided by them is of average or poor quality. Contamination is found to be highest in water from tankers in Mussoorie.

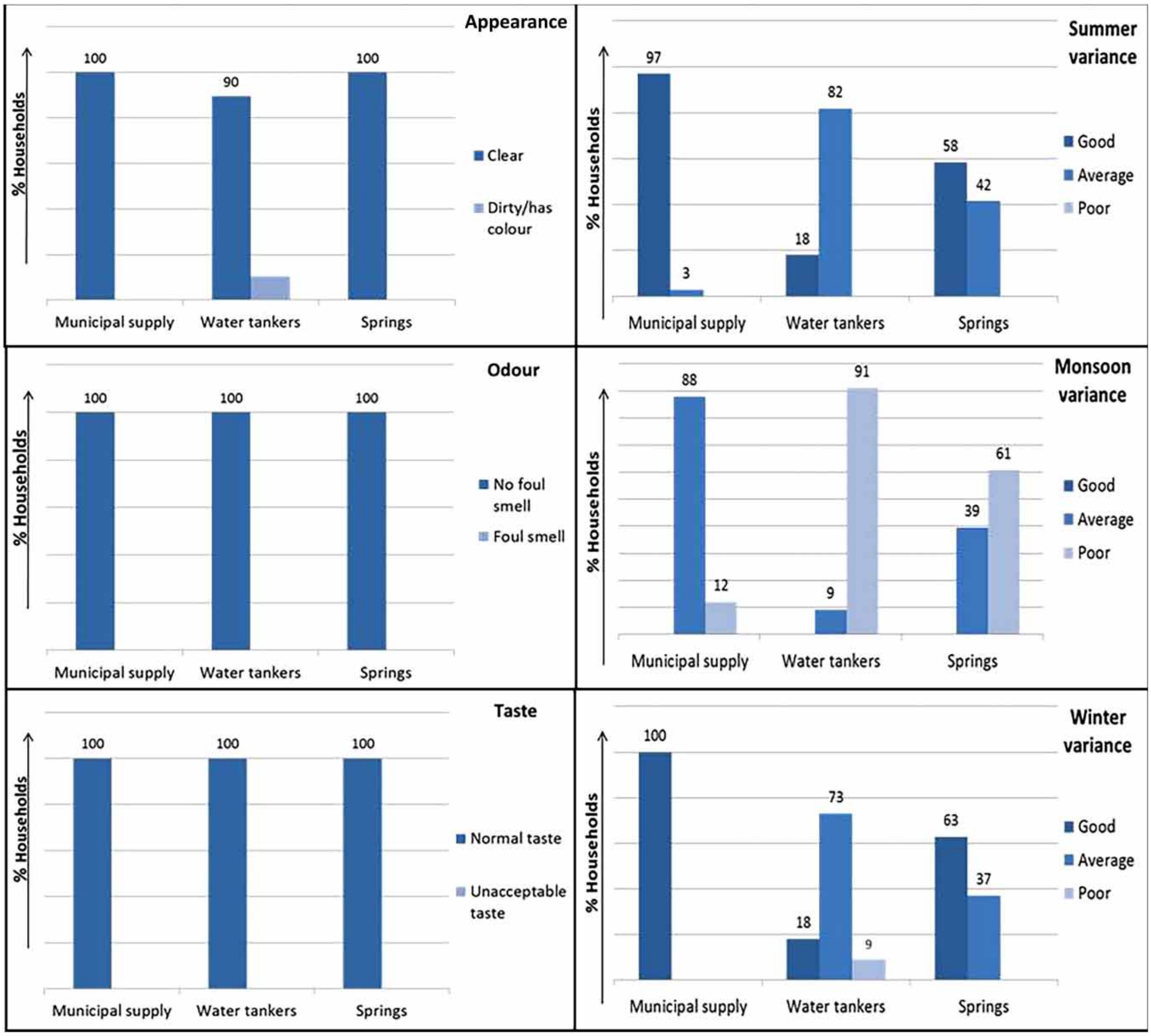

Fig. 6. Water quality and seasonal variability – Mussoorie.

Water consumption

Comparative analysis

Data collected during our survey suggest that most people in different wards of Mussoorie receive between 46 and 80 lpcd (Figure 8) and those in Devprayag even less, between 27 and 35 lpcd (Figure 9). When compared against the prescribed standards of 135 lpcd (CPHEEO manual) or the optimal access of 100–200 lpcd (WHO), these figures clearly show that the residents of Mussoorie and Devprayag only have intermediate levels of access to water.

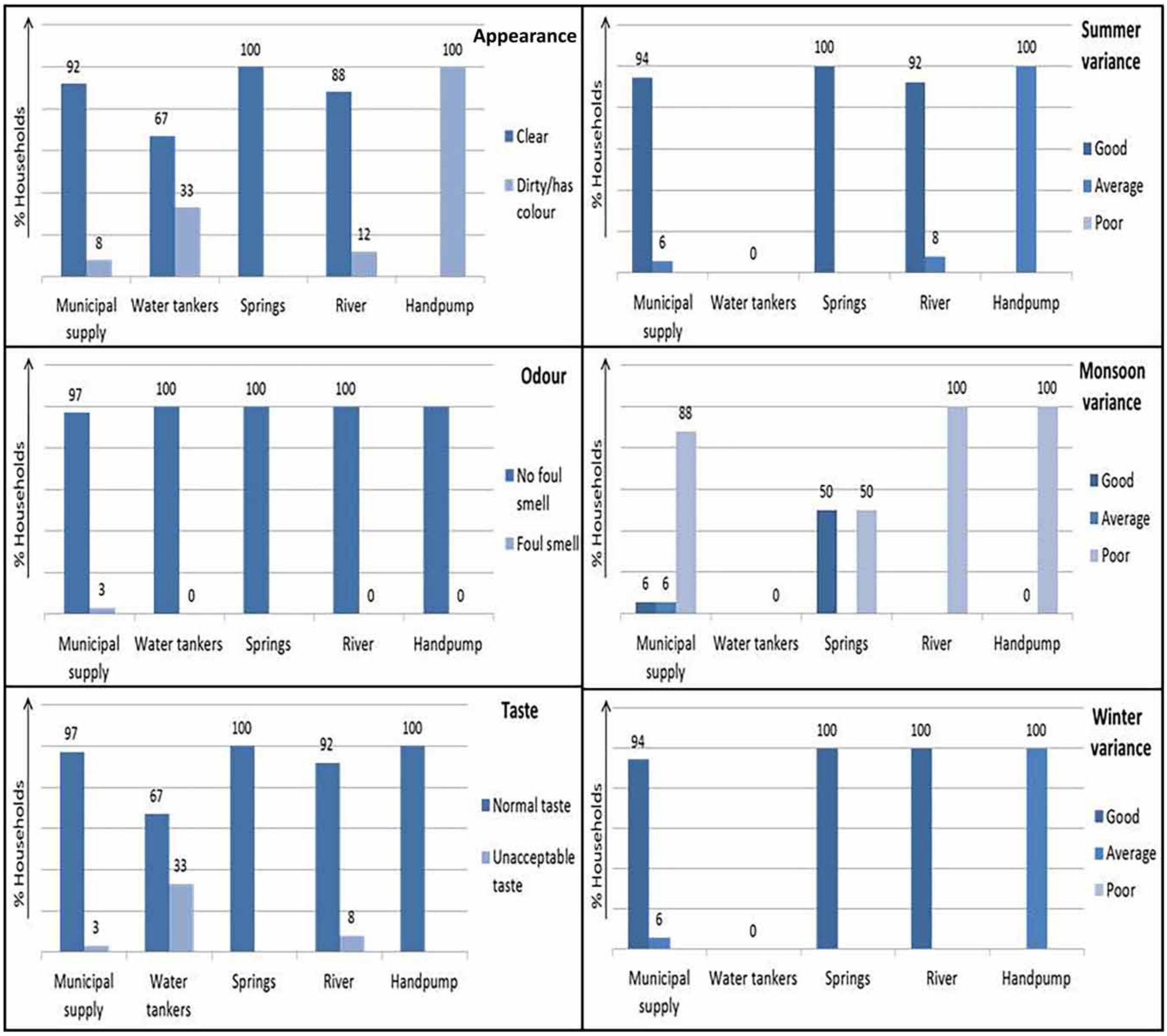

Fig. 7. Water quality and seasonal variability – Devprayag.

We now compare water consumption patterns across wards in each town. For Mussoorie, interviews with government officials revealed that even though wards 3 and 11 are considered to be 'peri-urban' and have the least number of roads, water consumption there does not differ much from the densely populated urban wards 5 and 8. This is because wards 3 and 11 receive a large number of tourists.

Interestingly, in Devprayag, water consumption is higher in cases where additional sources of water are available. For instance, per capita consumption is the highest in wards 2 and 4, despite them having the lowest population, as water is readily available not only from a primary source but also secondary sources – the River Ganges and spring water.

Conversely, respondents in ward number 2 in Devprayag consume less water than other wards as other sources are not as readily accessible to them. Many households in this ward do not have any private water connection and rely on the public stand post and river water.

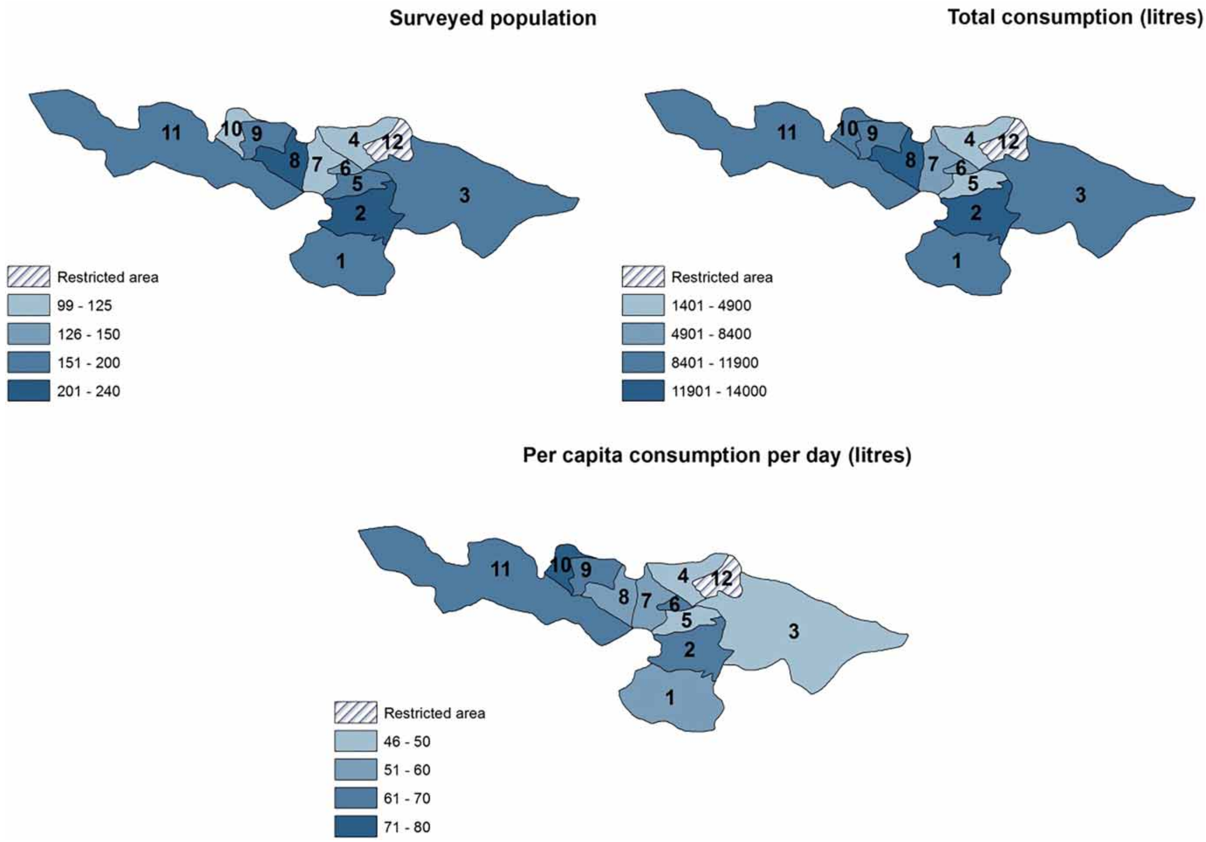

Fig. 8. Ward-wise water consumption in Mussoorie.

Thus, it is clear that having alternative sources of water in the form of springs and river water besides a municipal supply ensures greater availability and is reflected directly in the volume of water consumed by the residents interviewed.

Water collection practices

Received wisdom regarding social norms is that women are primarily responsible for water collection in households located in mountain towns. Our analysis found some variation between the two towns. Around 10% of families surveyed in Mussoorie and 69% in Devprayag stated that only adult females take the lead in water collection (Figure 10). The lower figure for Mussoorie may be due to differences in sociocultural setting; Devprayag appears to be more conservative and less urban.

In the remaining households surveyed in Mussoorie that collect water, responsibility is shared equally. In a crisis situation, all members of the family are engaged in water collection, resulting in loss of time required for other purposes such as education for children, jobs for earning males and females, and reproductive roles for females.

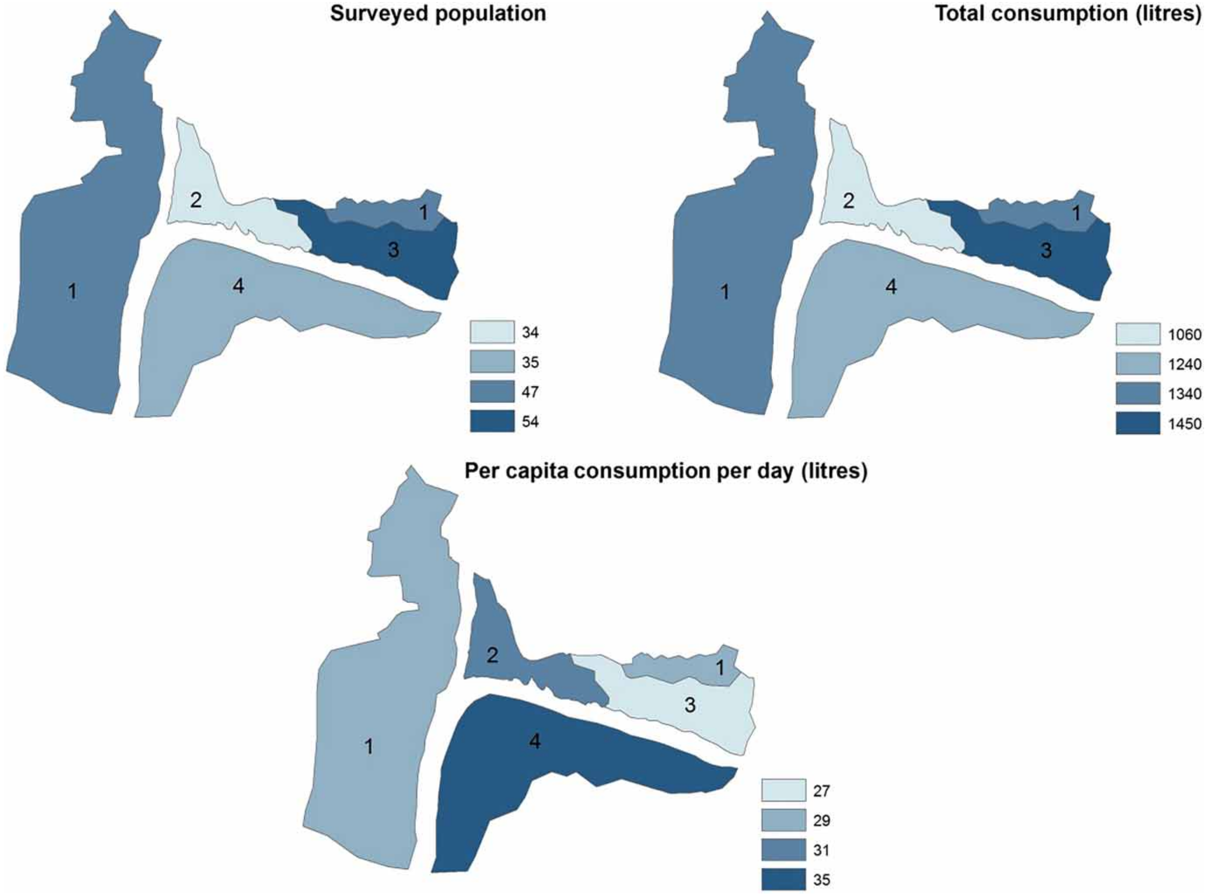

Fig. 9. Ward-wise water consumption in Devprayag.

Climate change scenarios in both towns

Perceptions of respondents

In both towns, elderly residents were asked about their perceptions regarding changes in climate over the last 30 years. A majority of the residents in both towns perceived rising winter and summer temperatures, and delayed arrival of the monsoon. They also perceived an increase in the intensity of 'short duration heavy showers' and a resultant reduction in the number of rainy days (Figure 11).

Modelling projections for climatic variables

We used Worldclim datasets (http://www.worldclim.org/) to understand the current trends and future projections of the following climatic variables for Mussoorie and Devprayag: (a) annual mean

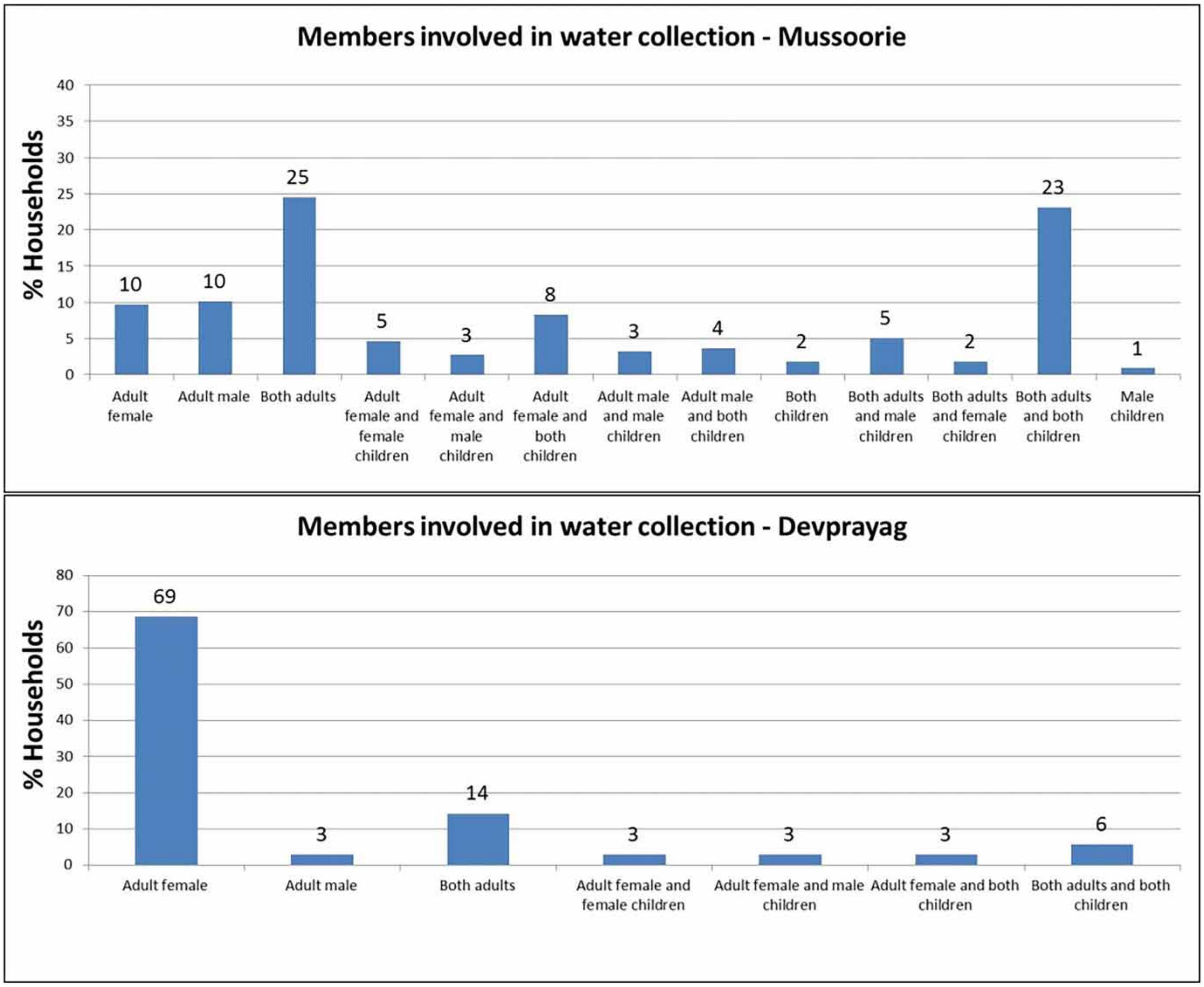

Fig. 10. Members involved in water collection in Mussoorie and Devprayag.

temperature; (b) maximum temperature of the warmest month; (c) annual precipitation; (d) precipitation during the wettest quarter; and (e) precipitation in the driest quarter. The current climatic conditions represent the period 1960–2000. The future conditions were downscaled global climate model data from CMIP5.

Tables 6 and 7 show a range of temperature rises in the mid-term future. As temperatures rise, people and animals need more water to maintain their health and thrive. Increased water demand can be expected due to the rise in temperature.

Tables 6 and 7 also show different variables of precipitation to understand the effects of climate change. Overall, annual precipitation is expected to increase from 2,003–2,728 mm to 2,063–2,859 mm in Mussoorie and 1,366–1,787 mm to 1,419–1,865 mm in Devprayag. The variability in precipitation holds great importance for seasonal water consumption.

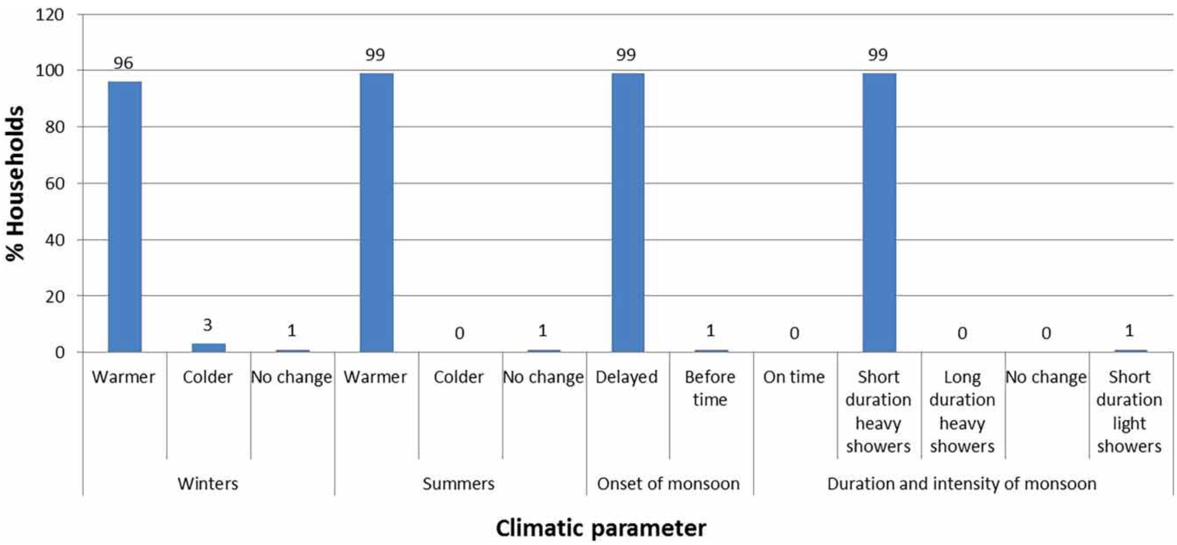

Fig. 11. Perceptions regarding the climate.

Table 6. Projected climatic variability – Mussoorie.

Variable	Current trends	RCP 4.5 (2050)
Annual mean temperature (°C)	13.1–20.7	15.3–22.8
Maximum temperature of the warmest month (°C)	23.6–34.6	25.9–36.9
Annual precipitation (mm)	2,003–2,728	2,063–2,859
Precipitation in the wettest quarter (mm)	1,412–2,184	1,490–2,316
Precipitation in the driest quarter (mm)	111–123	97–110

Table 7. Projected climatic variability – Devprayag.

Variable	Current trends	RCP 4.5 (2050)
Mean annual temperature (°C)	17.1–22.6	19.3–24.5
Max temperature of the warmest month (°C)	29.5–37.4	31.8–39.7
Annual precipitation (mm)	1,366–1,787	1,419–1,865
Precipitation in the wettest quarter (mm)	942–1,286	996–1,370
Precipitation in the driest quarter (mm)	88–107	81–90

Perceptions regarding changing water availability and solutions

Challenges in accessing water (Figure 12)

At the basin level for both towns, the biggest challenge perceived in terms of accessing water by 70% of respondents is the limited hours of supply. Participants indicated that they have observed a reduced discharge over their lifetimes in springs from which they source water, and a reduction in municipal water

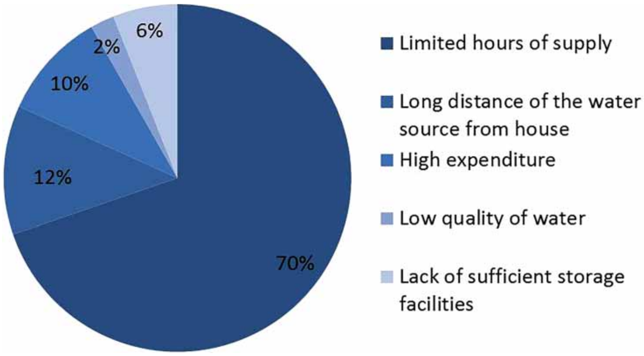

Fig. 12. Most critical challenges in accessing water (basin level).

supply, which is also sourced from springs. They reported witnessing events of 'no water supply' at a stretch of 3 days at least twice a year in Mussoorie and 15–20 days in Devprayag during the monsoon season. Thus, when the municipal supply gets disrupted during the lean season, they are unable to fall back on spring sources closer to the town as their discharge is low. This leads to competition for access to water. Residents also have to invest additional time in standing in long queues at public taps for fetching water.

Second, 12% of the respondents perceived 'distance' as a barrier in accessing water. This includes both the distance from which water is sourced, and the distance that residents have to travel in times of crisis to collect water. In Devprayag, the next major nearby source is the river Ganges but that itself carries mud and debris. There is also the risk of flooding during the monsoon and therefore fears of approaching the river then.

According to the respondents, the overall costs incurred presently on accessing water are high. This is the case not only because the water is being sourced from distant sources, but also because the system is vulnerable to natural hazards occurring in the mountainous terrain. As well, additional costs are incurred in purchasing water from private tankers. Not just quantity, but the deteriorating quality of water was also highlighted. Respondents complained of an occasional unacceptable odour and taste. Silt and even insects can be seen in the water during the monsoon.

Reasons for changing availability of water (Figure 13)

Both the towns are rapidly urbanizing – if one accounts for their floating populations as well – and hence their demand for water is increasing. Also, while Devprayag receives pilgrimage tourists, Mussoorie receives tourists on leisure trips, which further adds to the demand for water. The pressure on the water supply is compounded during the pilgrimage and tourist seasons.

The concretization of green slopes and deforestation in nearby areas is impeding the recharging of aquifers. Rainfall is becoming erratic and the number of rainy days is perceived to have reduced. Thus, collectively, the 'depletion of resources due to high demand' (44%), 'decrease in rainfall and increase in temperature' (17%) and 'mismanaged water resources' (22%) are seen as the major reasons for the water crisis.

In Mussoorie, Jal Sansthan is still running machinery installed during British rule and some parts require urgent replacement. The damage faced by such infrastructure is aggravated by extreme climatic events. The flood disaster event of 2013 severely damaged the water supply system in Devprayag,

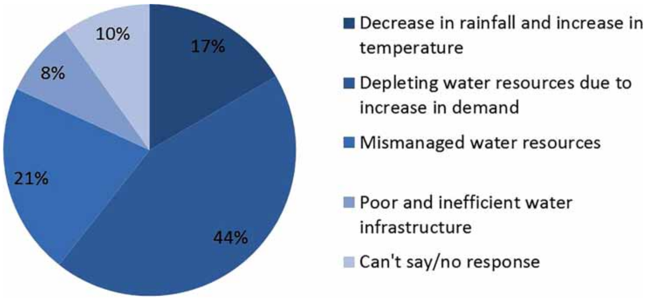

Fig. 13. Reasons for the water crisis.

disrupting the supply for 10–15 days. Deforestation, in order to accommodate more people, for making space for houses and roads, has led to a loosening of the earth, thus making the region more susceptible to landslides which can damage pipes.

Solutions for the water crisis

Since issues of water crisis in both towns are being attempted to be solved by bringing water from newer sources, almost half of the respondents identified with that as a solution (Figure 14). In Devprayag, residents suggested bringing an additional supply through a water uplift scheme from the Ganges River as they see its water as a surplus nearby source.

About 14% suggested 'rejuvenation of springs' as a solution. Another 12% felt that installing rainwater harvesting structures could help to some extent.

Coping strategies undertaken

Residents in both Mussoorie and Devprayag cope by diversifying their sources and accessing water directly from natural sources in times of crisis. With climate change bringing additional uncertainty, having multiple options to rely on seems all the more desirable, and even necessary.

People in the two towns have varied ways of coping, owing to differences in geographical features and sociopolitical conditions. In Mussoorie, residents fall back on accessing water stored in public

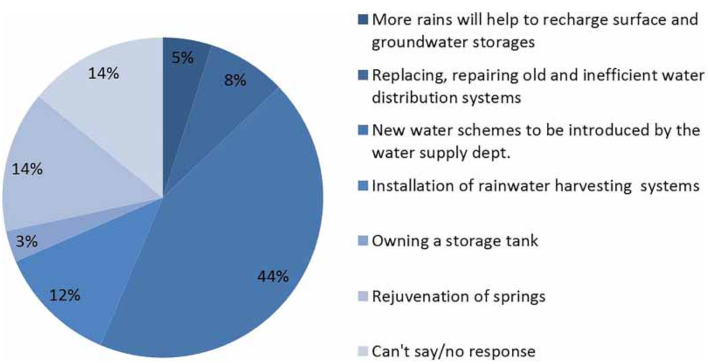

Fig. 14. Solutions offered to deal with the water crisis.

tanks or springs, whichever is closer. Many respondents said they also cope majorly by storing water in as many containers as they can. Families in Mussoorie are also forced to curtail their water consumption to a major extent. This can give rise to issues of health and hygiene, especially in settlements with a common toilet facility, as there is limited water available per person. Using private water tankers is another important measure adopted (Figure 15(a)).

In Devprayag, around half the surveyed families fetch water from the river flowing nearby. Nearly 22% rely on spring sources near their settlement. Collecting water from municipal water tankers is another way to cope (Figure 15(b)). However, as discussed earlier, houses located down the hill find it difficult to access private tankers in Devprayag.

Discussion and conclusions

Urban water management systems in hill cities and towns currently focus only on augmenting the water supply system from different sources. However, there is a need for multiple solutions or practices with the potential to meet the water needs of the present and future, without altering the urban hydrological cycle. Therefore, this calls for reforms in the urban water sector and for developing a framework that takes into account the topography, climate, ecology and the socioeconomic, institutional, administrative and political characteristics of an urban area before evolving sustainable options for it. A combination of soft, hard, structural and non-structural measures can be introduced and implemented within such a framework, including water supply and demand management (Kumar, 2014). Examples of some interventions could be: water conservation; the use of non-conventional sources such as storm water, roof run-off and waste water; storm water management; leakage reduction; water meters and pricing; building institutional capacities to manage water; and community and private sector participation in urban water management. Having analysed the problem in previous sections, we conclude that to improve the urban water system in Devprayag and Mussoorie, working on both the demand side and supply side management is needed. With a changing climate posing new challenges, multidisciplinary strategies need to be incorporated in the urban water management system.

This following section discusses measures that can be adapted within a framework to decrease the vulnerabilities of the hill communities to water stress without compromising environmental sustainability.

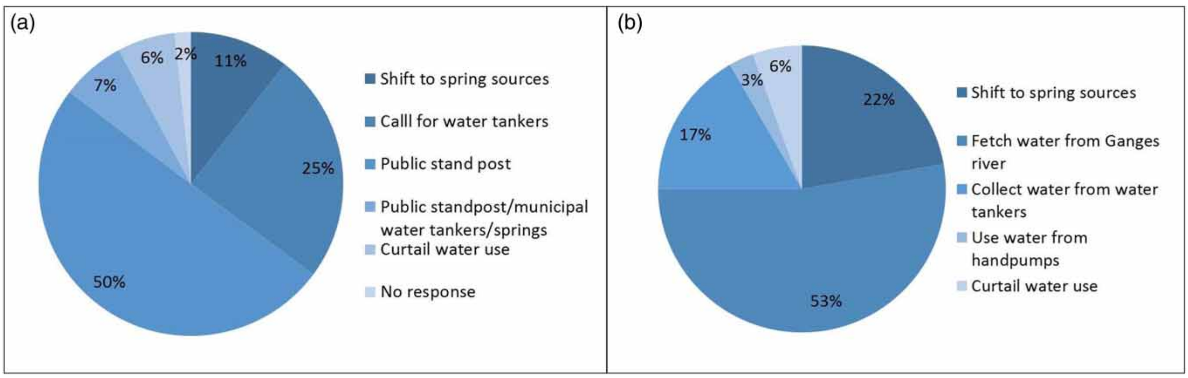

Fig. 15. Coping strategies undertaken: (a) Mussoorie and (b) Devprayag.

Spring protection programmes

Both towns are heavily dependent on spring sources for their water supply and drinking. This is the case for the entire Himalayan region. Around 90% of the drinking water supply in the mountainous part of Uttarakhand is spring-based (Niti Aayog, 2017). However, the springs are in crisis and their discharge is declining due to environmental degradation, changing land use patterns and a warming climate. A survey in Uttarakhand found that 30% of the springs in the region had almost dried up and an additional 45% were on the verge of going dry (Chakraborty, 2013). Due to the changing climate, water supply schemes falling under Devprayag's jurisdiction have recorded a decrease in discharge, at the source, of more than 50% over the last three years (Sharma, 2016). Similarly, spring sources in and around Mussoorie have displayed a noticeable reduction in discharge during the last decade. Two sources, Jinsy and Bhilaru, responsible for the largest portion of total water supply in the town, have reduced by 20%, from 450 litres per minute (lpm) in 2008 to around 365 lpm in 2017 (Jal Sansthan, 2017).

In this context, state-wide springshed management programmes and science-based and community-led springshed management interventions are extremely relevant for growing mountain cities in the IHR, and an effective way to enhance discharge in springs, even during the lean seasons. There have been many community-centric initiatives regarding springs in the states, but they are largely focused on distribution rather than regeneration.

An exception is the Dhara Vikas programme in Sikkim. It aims to catch surface run-off water and use it to recharge groundwater sources by digging staggered contour trenches and percolation pits, after identifying the specific recharge areas based on principles of geohydrology. The Rural Management and Development Department (RMDD) of the Government of Sikkim conceptualized and led the Dhara Vikas initiative to revive dying springs in the state. It is supported by different stakeholders, including NGOs, private organizations and the local communities. The communities are themselves engaged in this process of mapping springsheds, and aid the revival of springs at the village level. End-users were identified and trained as parahydrogeologists for monitoring and managing springs. This helped rejuvenate many springs in the region (Tambe *et al*., 2012; Niti Aayog, 2017). The Niti Aayog report recognized that in order to replicate successful examples such as Dhara Vikas in other places, the demand for initiating regeneration must come from the communities themselves, and that state departments can support such initiatives with the help of NGOs. However, for the uptake of such a programme at the regional scale, the participation and support of state and local governments is required. The fact that some of the success stories, such as Dhara Vikas in Sikkim, have been led by state governments clearly demonstrates the important role that governments can play in the effective implementation of springshed management programmes. NGOs can also be involved in generating awareness within the community and demystifying the science of springshed management (Niti Aayog, 2017). Similarly, a formalized methodology in this regard has been recently produced by a consortium of practitioners which takes into account all the above points and can be referred to for future spring revival initiatives (Shrestha *et al*., 2018).

Storm water management

Run-off is high in mountainous areas due to the incline. Rising urbanization accentuates run-off generation, due to the increase in impervious surfaces, leaving less space for infiltration. In traditional urban water systems, storm water is considered a nuisance and is not tapped and used. If storm water were collected and treated, it could be used to augment local storage or local water bodies.

There are open drains in both Mussoorie and Devprayag, and there is no provision to collect and treat storm water before its outlet into the river. Storm water management interventions can be structural and non-structural. Structural measures include actions that tap and reuse storm water; non-structural measures are practices that reduce the amount of run-off generated. Mountain communities can supplement their water supplies through rainwater harvesting. Harvesting one's roof water can reduce the dependence of households on municipal water and also make it cost-effective. It can also minimize the use of municipal treated water for non-potable use (Che-Ani *et al*., 2009). There are no existing non-structural storm water control measures in Mussoorie and Devprayag. However, certain measures undertaken by the PWD, the Mussoorie Nagar Palika and the local public can qualify for structural storm water management measures. These include the construction and maintenance of culverts, drains, aqueducts and retaining walls, locally called *pushtas* in different locations. These structures are built and maintained primarily to avoid waterlogging and flash floods in the town.

Wastewater treatment

If treated wastewater is reused, it reduces the fresh supply needed at source, and increases the availability of future water supply. However, both Mussoorie and Devprayag are devoid of wastewater treatment plants. In Devprayag, a sewage treatment plant (STP) with a capacity of 1.4 MLD began operating in 2017, but only one ward out of four is connected to the STP. As even in that ward only 20% of houses are connected to the sewer lines, the STP is not receiving enough wastewater and is running at one-fourth capacity.

In Mussoorie, STPs exist but are not functional. As per the information from key informant interviews (KIIs), construction began in 2012 and was completed in 2–3 years. However, connections were not allotted to all the households and the households with the connections are waiting for these STPs to begin functioning. According to local opinion, these STPs cannot function as the volume of water needed to run the STPs is not available in the town. Therefore, the present practice of sewage disposal at the individual and community level continues to be the use of septic tanks.

Regularization of tariffs

Water utilities have displayed no focus on volumetric pricing or the metering of municipal supply water. The tariff for water supply needs to be regularized, and should include production and supply costs. Research has shown that domestic tariffs are heavily subsidized in Indian cities (ADB, 2007).

There is no metering system presently in either Mussoorie or Devprayag, and no analysis as to whether the costs of production and supply of water are being met. Experts have argued that metering domestic water supply will help reduce unaccounted water losses in utilities (ADB, 2014). The pricing of water on the basis of volume used, for which metering is a precondition, will encourage urban water users to reduce wastage, thereby also reducing their monthly water bill (Bassi & Kumar, 2012). Whereas the main reason for distribution losses is poorly maintained infrastructure, unbilled and illegal connections are the biggest causes of unaccounted for water losses. Tariff regularization or water metering would also improve the financial condition of the water utilities as it would help increase their revenues.

Capacity-building

The capacities of the line departments or institutes involved in water management should be strengthened so that their ability to manage water resources in a sustainable manner also increases. In keeping with this, the capacities of various government departments linked to springshed usage or management in both towns should be built, as springs are the primary source of water in both. The capacities of consumers should also be raised, and there should be initiatives stressing the involvement of communities, especially women, leading to the increasing role of communities in inclusive urban planning. Inter-state cross-learning and support of experts from across the states should also receive focus for enhancing capacities.

Improving the governance structure

Besides the inefficient management of water supply systems, multiple institutional arrangements and their isolated style of functioning add to the problem (Bassi & Kumar, 2012). During KIIs in Devprayag, it was found that the tehsil office, which keeps a record of population, had little communication with the Jal Sansthan in planning and designing new initiatives. Thus, an augmented supply line with support from the ADB, planned for ten years, was set up not taking into account upcoming educational institutions in the area, which will house 2,000 students.

Convergence with existing policies

Several existing development programmes like watershed ought to include the protection of springs from the externalities of infrastructure development, including roads. Such an approach would tie well with the Government of India's strategic focus on sustaining the Himalayan ecosystem in the context of climate change. A working group formed by the Niti Aayog identified 'Inventory and Revival of Springs of Himalaya for Water Security' as one of their themes for working on sustainable development in the Himalayan region. It recommended mainstreaming springshed programmes through a convergence with existing development programmes such as the National Mission for Sustaining the Himalayan Ecosystem (NMSHE), the Integrated Watershed Management Programme (IWMP) and the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), and activities under climate change cells in various states, among others (Niti Aayog, 2017).

Replicating the institutional framework

Efforts at creating and strengthening the institutional framework must be replicated across states. A policy framework is needed whereby governments play an enabling role in partnership with civil society and the private sector to facilitate management of springs at a localized level.

Database

Besides developing an online database, it would be useful to tag vulnerable villages and springs; upload discharge data and recharge measures if taken to rejuvenate those springs. Data on population (including the floating population), spring discharge, water quality, metering and municipal infrastructure need to be made available to keep a check on trends in demand, water withdrawals and availability (McKenzie & Ray, 2009; Niti Aayog, 2017).

In the context of the IHR, the important driving forces will be: (i) enhancing institutional/organizational/local capacities; (ii) the availability of finance to carry out the required training and recruitment; and (iii) the desire for making the water supply infrastructure (both physical infrastructure and human resources) more efficient and resilient; and (iv) developing public–private–civil society partnerships. The challenges to achieving the above could range from the lack of political interest and the lack of a policy framework to the lack of skills and knowledge to carry out the required training. However, efforts should focus on strengthening the driving forces, and articulating clear strategies, structures and arrangements for carrying out the required interventions, so that it may ultimately lead to a better and more efficient performance of the urban water supplying utility.

Also, the ignorance of ecological upkeep in the larger context of rivers, watersheds and aquifers has led to large gaps in practice and policy in developing a strategic and integrated response to water management in Himalayan towns. Thus, there is the need for a paradigmatic shift in water governance, from focusing on developing water sources to the management of water as a resource. More integrated and adaptive management approaches and innovations are key to enhancing urban water management systems of the Indian Himalayan Region. This also helps achieve global commitments of the country in terms of enhancing water security (Goal 6.1 SDG (UN Sustainable Development Goals), INDC (Intended Nationally Determined Contribution), 2012).

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