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Water availability, consumption and sufficiency in Himalayan towns: a case of Murree and Havellian towns from Indus River Basin, Pakistan

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Abstract

This study attempts to analyse the status of water availability, consumption and sufficiency in two Himalayan towns – Murree and Havellian from Pakistan's Indus Basin, using the primary data collected from 350 households, 26 town level focus groups and key informants. Findings revealed that groundwater is the main source of water on which around 85% of households are heavily dependent. Estimates of water availability, consumption and water sufficiency ratio (WSR) show that available groundwater is not sufficient (0.89) to meet the requirements for consumption in Havellian. However, in the case of Murree, available water is sufficient (1.92). Taking into account the national standards of water consumption, WSR estimates show that both towns have insufficient water availability (Murree: 0.68, Havellian: 0.50). There is evidence that in both towns, water is being mismanaged at household level. In addition, one-fifth of households reported that climate change has also affected the water availability in the towns over time. Factors such as rapid urbanization and population growth are likely to result in increased requirements of water in the future. Based on the findings, the study has suggested policy actions on protection, efficient use, diversification and governance of groundwater resources.

Keywords: Climate change; Governance; Groundwater; Himalayan towns; Indus Basin; Sufficiency ratio; Urbanization; Water availability; Water consumption

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Introduction

The Hindu-Kush Himalayan (HKH) region extends 3,500 km across eight countries – Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan – covering an area of almost 3.5 million square kilometres, and accommodating nearly 240 million people (Sharma *et al.*, 2018). Almost one-fifth of the population of the HKH region is accommodated in the mountain areas of the Indus River Basin that lies in Pakistan (Sharma *et al.*, 2018). Over the past three decades, the HKH region has observed a rapid growth in urban population (Tiwari *et al.*, 2018). In addition to the natural increase in population of the region, the in-migration from the adjacent peri-urban and rural areas to the urban centres, for accessing better livelihood options, is also contributing significantly to the population rise in Himalayan towns (Tiwari *et al.*, 2018). It has led to an increased pressure on water resources in the Himalayan towns.

Another important factor which is causing a significant impact in the outlook of Himalayan towns in the Indus Basin is climate change (Bolch *et al.*, 2012; Immerzeel *et al.*, 2013; Palazzi *et al.*, 2013; Lutz *et al.*, 2014; Shrestha *et al.*, 2015a). A recent assessment report (Wester *et al.*, 2019) has revealed that 36% of the volume of the glaciers in the HKH region will melt by 2100 even if the world manages to keep warming below 1.5 °C. If the temperature increases by 2 °C, around half of the volume of these glaciers is likely to melt. It will be more alarming for the Indus Basin, where snowmelt and glacier melt contribute nearly 80% of its water flow – compared to the Ganga and Brahmaputra, which are mostly dependent on rainfall. Due to a high rate of glaciers melting, the Indus Basin will have more water flowing in, but in an increasingly unpredictable manner. In the HKH region, winters are seeing more warming than the summers with high mountain areas being the most affected. Precipitation across the Himalayas of the Indus Basin is likely to increase by 5% on average by 2050 (Shrestha *et al.*, 2015a). In addition to losses in glacial mass, temperature rise, increased liquid precipitation, there are high chances of a decline in solid precipitation (Wiltshire, 2014). A growing mismatch may occur between the timing of peak flows and the requirements for water in achieving food security in the basin (Lutz *et al.*, 2014). Increased temperatures and precipitation in the Indus Basin are causing erratic changes in rainfall and runoff patterns, which can cause serious implications for the residents of the mountain towns of Himalayas in the Indus Basin (Lutz *et al.*, 2016). These impacts range from reduced water availability and food production from mountain agriculture (Rasul *et al.*, 2019), to severe hydro-meteorological disasters such as flash floods, droughts and landslides. These impacts are significantly precarious for Himalayan towns as the climate risk and vulnerability associated with mountain communities is generally greater as compared to that of the plains (Tshe-ring *et al.*, 2010; Hunzai *et al.*, 2011; Gerlitz *et al.*, 2015). Therefore, increased uncertainty in the availability of natural resources caused by climate change will further increase the vulnerability of residents of Himalayan towns.

Himalayan towns in the Indus Basin have limited water resources available for domestic use. The terrain of these towns limits harvesting of domestic water from rivers and streams (Smadja *et al.*, 2015). The biggest challenge is that water storage projects involve high initial capital costs due to the rugged topography in the mountains (Hussain *et al.*, 2019). These limitations place the water availability scenario of these towns under inherent check. Since surface water sources are marginal and water demand has started exceeding the supply, these towns are becoming water stressed. Many of these towns have per capita water availability below the national and international standards (Laghari *et al.*, 2012). The reduced water availability for domestic use has been compensated through overexploitation of groundwater as an adaptive strategy both at household and town level. Groundwater appears to be a substantial source of urban water security as it is the major source of domestic water in Himalayas of the Indus Basin (Qureshi, 2011). Most of the groundwater in Himalayan towns is accessed in the form of fresh water springs or extracted via tube wells. Groundwater is a vital source of domestic water and thus water security for urban areas in the Indus Basin. Increasing urbanization in Himalayan towns is also threatening the recharge zones of groundwater aquifers. At the current rates of abstraction, aquifer depletion seems imminent. Despite its significance for water security groundwater resources are often unexplored and understudied in the Himalayas (Miller *et al*., 2012; Smadja *et al*., 2015). Further, the knowledge base regarding utilization of groundwater in Himalayan towns of the Indus Basin is very limited (Andermann *et al*., 2012).

In the Himalayan towns of the Indus Basin, potential impacts of increasing urbanization, unsustainable urban development and climate change are set to exacerbate water stress. As a result, groundwater is increasingly supplanting the dwindling surface water supplies. This study attempts to analyse the current situation of groundwater availability, consumption and sufficiency in two Himalayan towns, i.e., Murree and Havellian, in the Indus Basin, using the primary data collected at both household and town levels. Moreover, the study also comprehensively investigates the key factors affecting water availability and consumption in the towns. To the best of our knowledge, this is the first study on comprehensive water availability, consumption and sufficiency analysis in the Himalayan towns in Pakistan's part of the Indus Basin. It is hoped that the findings of this study will significantly contribute to strategies and plans for urban centres' development in the Indus River Basin.

Study area and methodology

Study area

In the Indus River Basin, Himalayan towns are rapidly urbanizing, adding more pressure on groundwater resources. For this study, two highly urbanizing towns, i.e., Murree and Havellian, have been selected (Figure 1). These towns may present strong cases regarding the situation of urban groundwater sufficiency in Himalayas and the key factors influencing it. Murree is located in Rawalpindi District of Punjab Province in Pakistan. It is the most popular hill station of the country, lying at 2,300 m above sea level (masl), about 50 km away in the north east from the capital city Islamabad. It is situated in the sub-Himalayan foothills. Havellian is located on the famous Karakorum Highway, at about 833 masl, on the banks of the Dor River, and is the second largest municipality in Abbottabad District of Khyber Pakhtunkhwa Province in Pakistan.

In terms of climate, Murree and Havellian are different from each other. Murree is situated in a subtropical highland climate zone with mean annual precipitation of nearly 1,800 mm (NOAA, 1995) and mean annual temperature of 12.7 °C (Rasul, 2012). Conversely, Havellian is warmer with a mean annual temperature of 20 °C, and receives mean annual precipitation of nearly 1,200 mm (Climate-Data, 2018). Significant characteristics of both the towns are presented in Table 1.

An overview of the historical precipitation and temperature data shows a significant variability over time for both towns (Figures 2 and 3). In Murree, mean annual rainfall trend shows a decline. Mean annual maximum temperature shows a gradual increase, and mean annual minimum temperature shows a decline with a few exceptions of rise from 2004 to 2008. In Havellian, annual maximum temperature has shown a gradual rise (Figure 3). These changes in rainfall and temperature trends in both

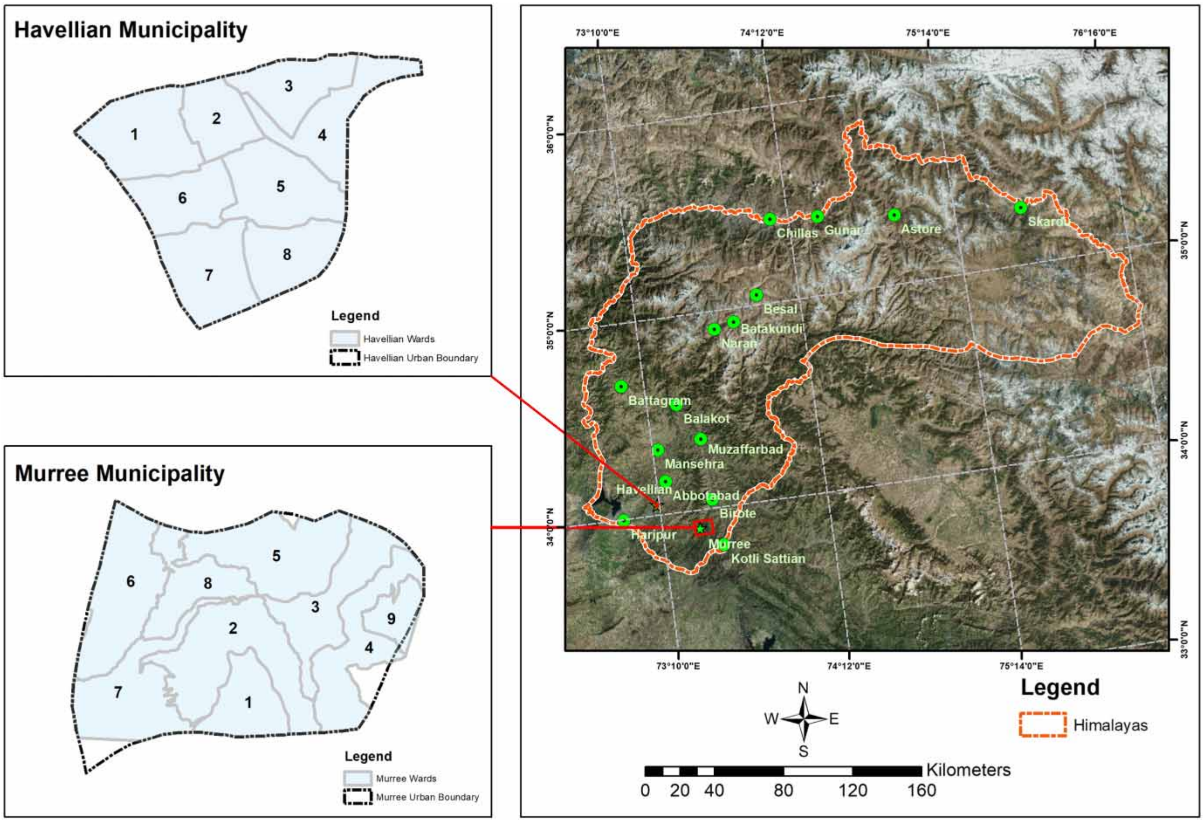

Fig. 1. Study towns in the Himalayas of the Indus River Basin.

Table 1. Study towns' salient features and characteristics.

Features	Murree	Havellian
Geolocation	33.55′ N and 73.23′ E	34.05′ N and 73.14′ E
Altitude	2,300 m (7,517 ft)	833 m (2,733 ft)
Municipal area	29.5219 km^2	0.89763 km^2
Administrative unit	Tehsil Murree, District Rawalpindi	Tehsil Havellian, District Abbottabad
Administrative unit area	434 km^2	406 km^2
Mean annual rainfall	1,789 mm/annum	1,194 mm/annum
Mean annual temperature	12.7 °C	20 °C
Climate zone*	Cwb (Sub-tropical, highland climate)	Cwa (Sub-tropical, humid)
Main water source	Groundwater (springs)	Groundwater (tube wells)
Sub-basin	Harro and Korang River Basin	Dorr River Basin

Source: Author's own calculations and District Profiles, Pakistan Bureau of Statistics.
*Koppen-Gieger Climate Classification (Kottek *et al.*, 2006).

towns have a direct implication for groundwater availability, as at present, both towns are relying exclusively on groundwater for domestic purposes.

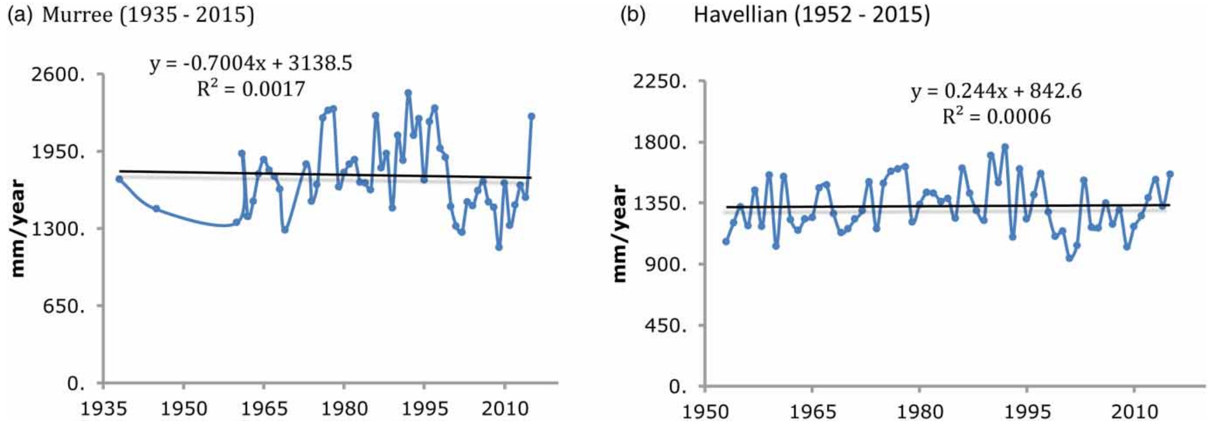

Fig. 2. Trends in mean annual rainfall. *Source:* Original data procured from Pakistan Meteorology Department.

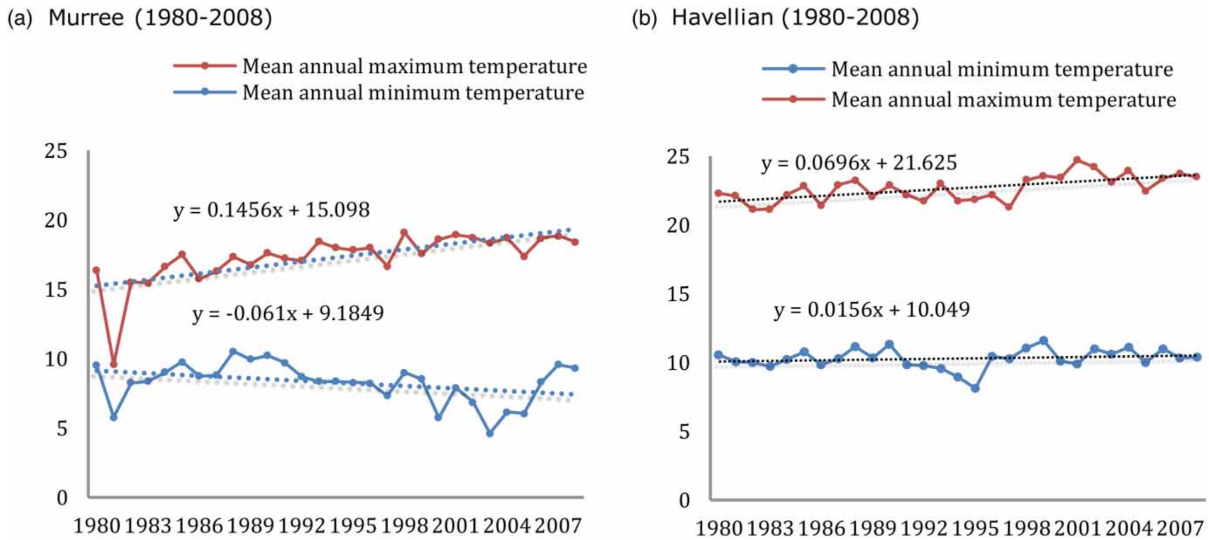

Fig. 3. Trends in mean annual maximum and minimum temperatures. *Source:* Original data procured from Pakistan Meteorology Department.

Study design and data collection

This study is mainly based on small-scale survey design. However, it also relies on some secondary data sources and qualitative information collected through focus group discussions and key informant interviews. For survey, Cochran's formula (Cochran, 1977) (Equation (1)) was used to estimate the sample size:

$$n = D \times \left[\frac{Z^2 \times (p) \times (1-p)}{e^2}\right] \tag{1}$$

In Equation (1), n denotes the sample size, and p is the percentage of households picking a choice (expressed as decimal = 0.5) and $(p) \times (1 - p)$ expresses an estimate of variance. Z denotes Z-value (1.96 for 95% confidence interval), and e denotes the margin of error ($\pm$0.065). It was planned to distribute the sample size across two towns. To compensate for any loss of statistical robustness in the sample distribution, a design effect 'D' (1.50) is considered in the formula. Using Equation (1), a sample size of 341 households was determined. However, in total, 350 households were actually surveyed. The sample was equally distributed among the two towns as the current population of both Murree and Havellian towns was approximately equal in 2017. Sub-samples of each town were distributed across streets/wards using the probability proportional to size (PPS) method. Within wards/streets, households were selected randomly using random route method. The household data were collected in 2017 using a standardized questionnaire that was digitized on an android-based application called AKVO-FLOW.

Secondary data sources for the study included: population data from Pakistan Bureau of Statistics (PBS) acquired through district census reports of districts Abbottabad and Rawalpindi (Pakistan Bureau of Statistics 1981, 1998, 2017); time series climate data for the past 30 years from Pakistan Meteorological Department (PMD) for daily temperature and precipitation of the towns of Havellian and Murree; and open source satellite images from Landsat and Sentinel for the years 1998 and 2017. Additional data were collected through focus group discussions (FGDs) and key informant interviews (KIIs). In total, 10 FGDs and 16 KIIs were conducted in the two towns, respectively, with community groups and the representatives of related government departments and NGOs. Some qualitative information was also collected on the areas of water sources, distribution mechanism, pricing, consumption, and governance issues in the towns.

Analysis tools

The study has mainly used descriptive statistics to analyse the data. In the questionnaire survey, data on household perception of the water resources situation, water sufficiency and climate change impacts on water resources were collected. However, the study has not entirely depended on this perception data. Additionally, it has quantitatively estimated water availability, consumption and sufficiency ratio, using both household and town level data. Quantitative estimations have helped in validating the household perception data. To assess the water sufficiency in towns, the study used the following equation (Equation (2)):

$$Si = \frac{W_a}{W_c} \tag{2}$$

where W_a is available groundwater, W_c is the consumed groundwater and S_i is the water sufficiency ratio (WSR). The value of WSR reveals the following outputs: $S_i < 1$, insufficient; $S_i > 1$, sufficient; $S_i = 1$, balanced or equilibrium state.

Water availability (Equation (2)) is based on two assumptions. First, at the town level, groundwater availability is equal to water extracted from ground sources for supply. Second, at household level, groundwater availability is equal to water stored in the house.

At household level, water consumption was estimated based on the quantitative data collected about the different uses of water in the household.

Statistical Package for the Social Sciences (SPSS-22) was used to conduct quantitative analysis of survey data and collected secondary data (i.e., population and climate data). Arc GIS 10.1 software was used to analyse the satellite images of Murree and Havellian to determine the increase in built-up area.

Results

Household characteristics

In both surveyed towns, the average household size is equal (seven members per household). However, in terms of type of house, there is a significant difference across towns. In Murree, more than 90% households have bricked or cemented houses. Conversely, in Havellian, only 56% households have bricked and cemented houses (Table 2). Moreover, in Murree, more than 90% of households own their houses. Conversely, in Havellian, nearly 30% of households live in rented houses. In Murree, the percentage of immigrating households is also higher compared to that of Havellian. In terms of income levels, in both towns almost 40% of households reported that their monthly income ranges from 151USD to 300USD per month (Table 2).

Table 2. Household socioeconomic characteristics.

		Towns	
Variable	Response	Murree	Havellian
Average household size (number of persons)	–	7	7
Average male household members		4	4
Average female household members		3	3
Respondent's education status (%)	Illiterate	12.0	12.6
	Primary	18.3	6.9
	Middle school	13.7	16.0
	High school	32.0	23.4
	Higher secondary	12.6	19.4
	Graduation	8	18.9
	Post-graduation and above	3.4	2.8
House ownership status (% households)	Rented	7.3	25.9
	Owned	92.7	74.1
House construction type (% households)	Brick/Cemented	89.8	56.4
	Mud/Thatch/Wooden	10.2	43.6
Migration status (% households) (immigrants)	Migrant	16.0	9.7
	Non-migrant	84.0	90.3
Toilet facility (% households)	Private	99.4	100
	Community	0.6	0
Household monthly income levels (income classes in USD) (% households)	<100	8.6	7.5
	100–150	25.7	12.6
	151–300	37.1	37.4
	301–500	15.4	25.9
	501–1,000	6.3	12.6
	>1,000	6.9	4.0

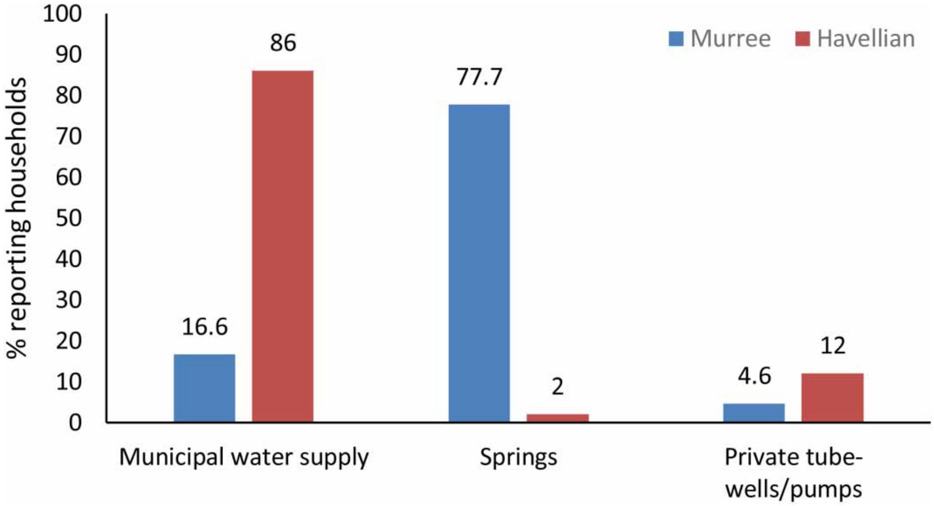

Fig. 4. Household water sources in selected Himalayan towns.

Main water sources

Survey data analysis reveals that in both towns, households are heavily dependent on groundwater sources, e.g., municipal water supply (mainly pumped by tube wells), springs and private tube wells/pumps. In Murree, almost 80% of households depend on spring water for domestic purposes (Figure 4), and in Havellian, 86% of households are dependent on municipal water supply. In Havellian, almost 5% and in Murree 12% of households depend on groundwater that is directly withdrawn at community level by using private tube wells/pumps.

In Murree, nearly 65% of households reported that the quantity of water available from springs is always sufficient, and 20% reported that water quantity is occasionally sufficient (Table 3). In Havellian,

Table 3. Household perception of water sufficiency.

Indicators	Response	Murree	Havellian
Sufficiency of spring water (% households)	Always sufficient	64	NA
	Occasionally sufficient	20	NA
	Never sufficient	4.6	NA
	Not applicable	11.4	NA
Sufficiency of municipal water to meet household water requirements (% households)	Always sufficient	9.14	57.7
	Occasionally sufficient	7.43	29.2
	Never sufficient	4	4.6
	Not applicable	79.42	8.5
Frequency of municipal water supply	Everyday	9.7	89.4
	Once in 2 days	5.7	8
	Once in 3 days	1.7	1
	Not applicable	82.9	1.6
% households reporting a change in water availability in last 20 years	70	43	70

NA, not available (data were not collected).

nearly 60% of households reported that water from municipal supply is sufficient to meet their water requirements, and almost 30% of households reported that supply is occasionally sufficient. Around 5% of households reported that they never get sufficient water (Table 3). Overall, 35% of households in towns reported that available groundwater is not sufficient to fulfil their domestic requirements. Around 90% of households receive municipal water every day, 8% receive water once in 2 days and just under 1% receive municipal water once in 3 days. More than 70% of households in Murree reported a change in water availability in the past 20 years. In Havellian, 43% of households reported a change in the water availability over the past 20 years (Table 3). In discussions, households in both towns reported seasonal fluctuations in water availability. In Havellian, less water is available in summer corresponding to increased overall demand, and in Murree, limited water is available in winter due to reduced discharge from the springs.

Water availability

Estimates of water availability at town level are based on the quantity of available water reported during the FGDs and KIIs conducted during the qualitative survey with officials of Town Municipal Authorities. In Murree, gross water availability (supply) is 7.02 MLD. However, after 25% conveyance losses, it reduces to net availability of 5.3 MLD (Table 4). The net available water is further divided across cantonment and civilian areas. Civilian users, including residential and commercial users, receive 2.9 MLD of water. The residential areas receive 60% of allocated water to civilian areas (1.74 MLD).

In Havellian, gross water availability (supply) is 1.7 MLD. However, after 10% conveyance losses, it reduces to net availability of 1.6 MLD (Table 5). The net available water is further divided across residential and commercial users. The residential areas receive 80% of net available water (1.252 MLD). Overall, there is less water available in Havellian (Table 5), compared to Murree (Table 4).

Conversion of town level water availability into litres per capita per day reveals that nearly 102 litres and 74 litres per capita per day water is available, respectively, in Murree and Havellian (Table 6). However, at household level, around 78 litres and 52 litres per capita per day water is stored. It implies that there is a substantial gap between town level water availability and household level water storage (Table 6). This is due to household level water losses, and direct use of supplied water without storing it. This indicates mismanagement issues of water at household level.

Water consumption and water sufficiency ratio

In Murree and Havellian, estimated per capita water consumption is 53 litres and 83 litres per capita per day, respectively (Table 6), which is significantly lower than the international standard of 100 litres per capita per day (WHO, 2003) and national standards of 150 litres per capita per day water required for consumption (Government of Pakistan, M.o.H.W., 1993). Water consumption in Murree is significantly lower than that of Havellian. This can be attributed to the weather differences in the towns. Murree is comparatively cooler (see sub-section *Study area*) and the people may consume less water for bathing and washing purposes. Estimate of water sufficiency ratio (WSR) reveals that available water is still sufficient to meet consumption requirements in Murree ($S_1 = 1.92$, $S_2 = 1.47$) (Table 6). However, In Havellian, available water is not sufficient (($S_1 = 0.89$, $S_2 = 0.63$) to meet the consumption requirements (Table 6). Taking into account the national standards of water consumption

Table 4. Water availability in Murree.

			Million litres per day (MLD)					
Access point	Water source	Date of commission	Daily supply (G)	After deduction of 25% conveyance losses (N)	Supply to cantonment areas (45% of N)	Supply for residential and commercial uses (RCU) (55% of N)	Commercial (40% of RCU)	Residential (60% of RCU) (water availability at town level to be supplied to households)
Dunga Galli	Surface water	1894	2.27	1.702	0.766	0.936	0.374	0.561
Dharjawa	Spring water	1974	3.5	2.625	1.181	1.443	0.577	0.866
Masoot	Spring water	1985	0.57	0.427	0.192	0.235	0.094	0.141
Shawalla	Spring water	1993	0.3	0.225	0.101	0.123	0.049	0.074
Khanitak	Spring water	2009	0.38	0.285	0.128	0.156	0.062	0.094
Total	–	–	7.02	5.265	2.369	2.895	1.158	1.737

G, gross; N, net; RCU, residential and commercial uses.

Table 5. Water availability in Havellian.

			Million litres per day (MLD)			
Access point	Water source	Date of commission	Daily supply (G)	After deduction of 10% conveyance losses (N)	Commercial (at 40%)	Residential (at 80%) (water availability at town level to be supplied to households)
Tube well 1	Groundwater	1978	0.567	0.510	0.102	0.408
Tube well 2	Groundwater	1993	0.3785	0.340	0.068	0.272
Tube well 3	Groundwater	2003	0.567	0.510	0.102	0.408
Tube well 4	Groundwater	2010	0.227	0.204	0.040	0.1632
Total			1.74	1.565	0.313	1.252

Table 6. Water availability, consumption and sufficiency ratio.

Indicators	Murree	Havellian
A. Water availability at town level (litres per capita per day)	101.70	74.43
B. Water storage at household level (litres per capita per day)	77.85	52.33
C. Difference of town level and household level water availability (litres per capita per day)	23.85	22.1
D. Water consumption (litres per capita per day)	53.0	83.0
E. Water sufficiency ratio ($S_1 = A/D$)	1.92	0.89
F. Water sufficiency ratio ($S_2 = B/D$))	1.47	0.63
G. *Water sufficiency ratio ($S_3 = A/150$)	0.68	0.50

*Ratio estimated taking into account the national standards of water consumption (150 litres per capita per day).

(150 litres per capita per day), estimated WSR shows that both towns are facing water insufficiency ($S_3 = 0.68$ and 0.50, respectively, in Murree and Havellian) (Table 6).

Factors affecting water availability

Climate change, inadequate governance and demographic changes are key challenges affecting the water availability at both household and town levels. A majority of households in the study towns perceived changes in climate in the last 20 years (Table A1 in Supplementary Materials). Almost one-quarter of households in each town reported that changes in rainfall and temperature patterns are resulting in changes in water availability (Table 7). Among governance and management factors, more than 90% of households in both towns reported that inadequate institutional support to protect water resources is resulting in either a decline or fluctuation in water availability. Almost 30% of households in Havellian and one-fifth in Murree

Table 7. Household perception of reasons of change in water availability.

Reasons for change	Murree (% households)	Havellian (% households)
Decrease in rain and increase in temperature	24.1	22.7
Overexploitation of groundwater resources	18.3	28.5
Mismanaged water resources	18.8	12.6
Poor and inefficient water infrastructure	9.9	6.4
Inadequate institutional support to protect water resources	95	92.5
Others (increase in population and urbanization)	2.9	3.5

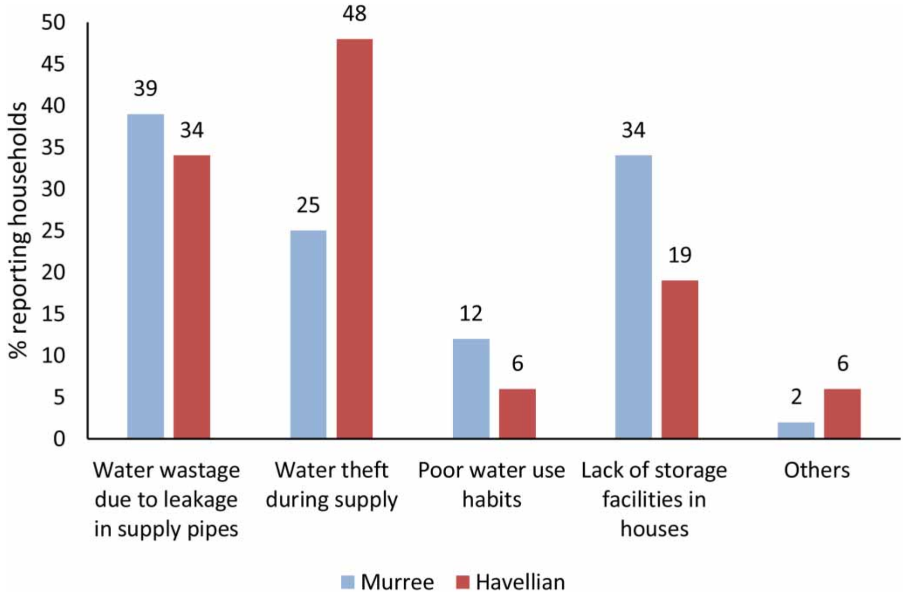

Fig. 5. Household perception of losses to available water.

perceived that overexploitation of groundwater resources results in changes in water availability. Around 10% in Murree and 6% in Havellian reported poor and inefficient water infrastructure as the reason of change. In both towns, around 3% of households reported that demographic changes such as increasing population and urbanization are impacting the household water availability (Table 7).

Households also reported some key factors resulting in losses to available water in the towns (Figure 5). These factors may be among the possible reasons for the gap between quantities of available water at town and household levels (Table 6). In Murree and Havellian, around 40% and 35% of households, respectively, reported that leakage in pipes, while supplying water from sources to households, is resulting in water losses. In Murree, one-quarter of households reported water theft as a reason of water losses during supply. However, in Havellian, nearly 50% of households reported such a reason (Figure 5).

In Murree, around 35% households reported that they do not have adequate water storage facilities at home. In Havellian, one-fifth of households reported inadequate storage facility as the reason of water losses. In Murree and Havellian, respectively 12% and 6% households reported that poor water use habits such as direct excessive use of water for domestic purposes (without storing), kitchen gardens, washing vehicles, and bathing pet animals result in water losses (Figure 5).

Overall, household perception for reasons of change in water availability (overexploitation and mismanagement of available water, and poor infrastructure) (Table 7), and perception of losses to available water (Figure 5) reveal that available water is being mismanaged during supply and use at household level in both towns.

Factors affecting water consumption

Among the factors affecting water consumption, the most important factors are rapid urbanization, high population growth and changing socioeconomic status of households. In the past three decades,

Table 8. Population in study towns.

	Years	Murree	Havellian
Population	1981	10,744	10,378
	1998	13,975	12,016
	2017	17,079	16,821
	2030	19,938*	19,780*
	2050	26,142*	26,262*
Population growth rate** (%)	1981–1998	1.56	0.87
	1998–2017	1.06	1.79
Population density (persons/km^2)	1981	364	11,531
	1998	473	13,351
	2017	579	18,690

Source: Pakistan Bureau of Statistics 1981, 1998 and, 2017.
*Projected population.
**Average annual compound growth rates.

population and population densities have shown a significant rise in both Murree and Havellian. The growth rate of population in Murree has grown at the rate of 1.56% between 1981 and 1998 and 1.06% between 1998 and 2017. Similarly, the growth rate of population in Havellian was 0.87% between 1981 and 1998 and 1.79% between 1998 and 2017. The projections show that both towns will have a population of more than 25,000 by 2050 (Table 8). A rise in population has a strong impact on water consumption through adding more pressure on available water at household level and nearby springs as in the case of Murree. Havellian is also gaining increasing importance as a result of upcoming major transportation infrastructure projects connecting the central parts to the north of Pakistan. Hence, urban growth and expansion of the town is imminent in the near future.

In Murree and Havellian, there has been a drastic increase in urban area in the past two decades. The land use has changed significantly in Havellian, with around a 22% addition in the built-up area in the last 19 years. The scenario is similar for Murree, with about a 22% addition to the built-up area in the last 19 years (Table 9). Urban sprawl in both towns indicates the fast rate of urbanization in the two towns (Figure 6(a) and 6(b)). Urban sprawl in any area affects water consumption in such a way that it increases economic activity, which first increases non-residential water consumption such as commercial or industrial water consumption. Urbanization promotes population growth via in-migration and results in changes in lifestyle and socioeconomic status of local people. It may result in an increase in domestic water consumption.

Table 9. Land use change in Murree and Havellian.

Town	Total area (km^2)	Built-up area 1998 (%)	Built-up area 2017 (%)	Change (%)
Murree	29.52	10	31	21
Havellian	0.90	63	85	22

Source: Author's own calculation using GIS techniques and satellite images of Landsat and Sentinel.

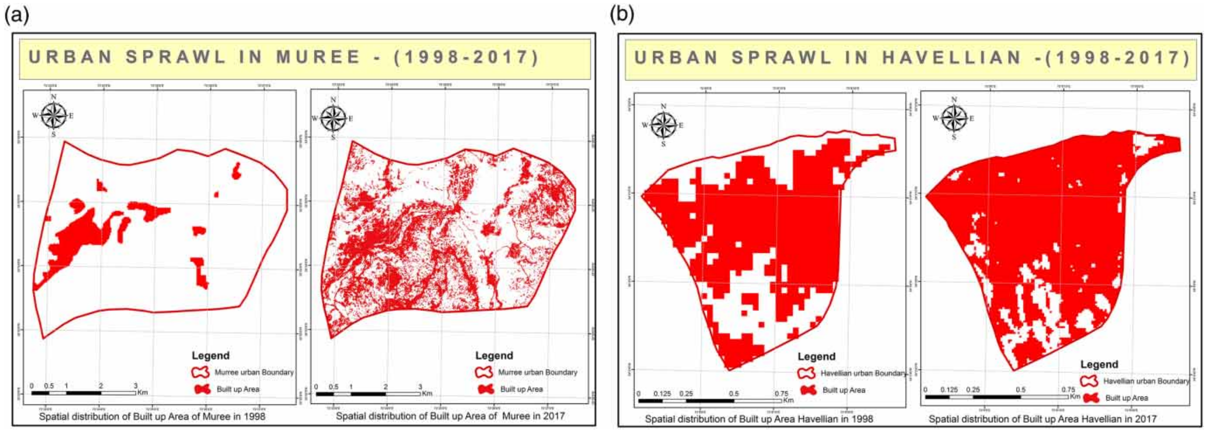

Fig. 6. Land use change and urban sprawl in Murree and Havellian 1998–2017.

Discussion

Due to increasing population, limited surface water storage and increasing impacts of climate change, pressure on groundwater has increased tremendously in Pakistan, including northern Himalayas, over the past several decades (Bhutta & Alam, 2006). Results of this study have also revealed that the populations in two Himalayan towns – Murree and Havellian – are highly dependent on groundwater resources. In Murree, around 80% of households are dependent on spring water (supplied by municipality as well as direct use). In Havellian, 86% of households are dependent on municipal water supply which is mainly fed by groundwater pumping (Figure 4). In both towns, nearly 5 to 12% of households also directly pump groundwater to fulfil their consumption requirements. In Murree, more than 15% of households perceived that spring water is not sufficient to fulfil their consumption requirements. Likewise, in Havellian, around 13% of households reported that municipal water supply is not sufficient. In both towns, 20–30% of households reported that water supplies are occasionally sufficient (Table 3). These reported/perception data are validated through quantitative estimates. Estimates of water availability, consumption and sufficiency ratio showed consistent results for Havellian, where water requirement for consumption is higher than water supplies. However, in the case of Murree, quantitative estimates showed the water supplies are sufficient to meet consumption requirements. Sufficiency ratio is based on average availability and consumption. Thus, it may not reflect the number of households who face water insufficiency. More importantly, sufficiency ratio based on national standards of water consumption shows that both towns have insufficient water supplies to meet the consumption requirement of their respective populations (Table 6).

In both towns, it is found that at household level, a significant proportion of supplied water is either being used directly without storing it or it is wasted due to mismanagement within households (Table 5). Around 20% and 30% of households, respectively, in Murree and Havellian reported that overexploitation of groundwater is impacting its overall availability. Likewise, around 20% and 13% of households reported mismanagement as the reason of change in water availability (Table 7). In the face of climate change, mismanagement of groundwater poses a serious challenge to overall sustainability of water resources. Climate change has already impacted the water availability in both towns, as reported by more than one-fifth of households (Table 7). If mismanagement and climate change continue to impact water resources, both towns may face serious water crises in the future. In particular, the gradual drying up of springs in Murree may result in a water stress situation in the town. In addition to risks to sustainability of water availability, water consumption requirements are also increasing gradually due to high population growth (Table 8) and rapid urbanization (Table 9 and Figure 6). Although most of the parts of the western Himalayas that fall in the Indus Basin are sparsely populated (Hassan, 2010), the case is not the same for some urban centres in these mountain areas, as Himalayan towns in the Indus Basin have witnessed an overwhelming growth in population over the past few decades. This growth in population is largely related to migration from rural areas to urban centres. Analysis of subsequent censuses in Pakistan establishes that the trend of migration remains from deprived and underdeveloped areas to large urban centres in the country (Gazdar, 2003; Hassan, 2010). The demographics of Himalayan towns of the Indus Basin have also rapidly changed due to the increase in trade between the neighboring countries and since most Himalayan centres lie along major trade routes, urbanization and population growth seems inevitable. This increase in population in the urban clusters of Murree and Havellian is similar to most Himalayan towns in the Indus Basin. The urban growth rate in northern Pakistan has remained uniformly high from 1981 to 2009 (Nazir & Schmitt Olabisi, 2015).

The future of water supplies to these Himalayan towns appears uncertain, while plans for sustainable management of aquifers remain a far cry (LEAD, 2016). High dependence on a singular water resource indicates the high vulnerability of Himalayan towns towards future hydro-meteorological shocks. In the absence of water conservation or development of alternative water resources in the Himalayan region, the urban water situation in the towns is set to become more precarious in the coming years. The region is warming at a rate higher than the global average (Shrestha *et al*., 2015a, 2015b). Future projections indicate that while total precipitation will remain constant, the number of rainy days will reduce meaning lesser but more intense precipitation events (Lutz *et al*., 2014). Furthermore, scientific literature suggests that urbanization increases surface runoff generated from precipitation and limits infiltration. Recent studies have now shown that increased urbanization can influence the timing and magnitude of precipitation, thus controlling the local climate of the urbanized area. This can be traced to 'urban heat island' effect, which affects the air circulation in urban areas. Moreover, increased carbon emissions in urban areas can also affect the local climate of the towns more adversely than rural areas (O'Driscoll *et al*., 2010). These climatic impacts will have direct implications on the water resource situation in the urban Himalayas.

Where regulations are scanty in terms of water accessibility to inhabitants of these towns, control over urban sprawl on groundwater recharge zones is also poor. This can have serious impacts on towns like Havellian, where groundwater availability is directly dependent on groundwater recharge. City planning and development agencies across Himalayan towns lack substantial strategies to control paving of groundwater recharge zones as is the case of increasing encroachment of urban population in the spring recharge zones of Murree area, as reported by key informants and focus groups alike. Increased urbanization leads to more paved surfaces which inhibit infiltration and thus the groundwater recharge (Leopold, 1968; O'Driscoll *et al*., 2010). The extent of urbanization in Himalayan towns, however, has soared within the past two decades, with significant losses to land cover at the hands of urbanization, as is evident from Figure 6 and Table 9.

The findings of this study are consistent with those from other urban centres in the HKH region. Urban population in all parts of the HKH region is also increasing rapidly. Singh *et al*. (2019) revealed that annual average growth rate (2001–2011) of population is 3–5% in the Himalayan urban areas of Bangladesh, India, Nepal and Pakistan. Migration from rural to urban centres for better economic opportunities is an obvious reason for the increased rate of urbanization (Rasul *et al*., 2019). It has further widened the gap (deficit) between water demand and supply in the urban centres. Singh *et al*. (2019) also compiled data on water demand and actual supply in 13 Himalayan towns of Bangladesh, India, Nepal and Pakistan. The study shows that all towns are facing a water deficit ranging from 30% to 88% (calculated based on data presented in Singh *et al*., 2019). Towns from the Indian Himalayas, e.g., Darjeeling, Kohima and Tansen face more than 80% water deficit, which is alarming, and likely to add more pressure on groundwater resources in these towns. Urbanization trends are almost similar to those in other countries of the Global South. By 2050, the urban population is projected to be around 66% of the total global population, with nearly 90% of the increase being concentrated in Asia and Africa (UNDESA, 2014). This increase in urban population is likely to have serious impacts on groundwater resources in urban areas.

In particular, in this study, it can be established that urbanization, climate change and lack of good governance are impacting the groundwater resources in Himalayan towns. All these factors are affecting current and future sustainability of this precious water resource. Thus, there is a dire need for effective and problem-centric groundwater policy for Himalayan towns and/or a need to have a clear directive for sustainable urban groundwater utilization and development in the National Policy on Water in Pakistan.

Conclusions

In the Hindu-Kush Himalayan (HKH) region, rapid urbanization, population growth, limited surface water storage and increasing impacts of climate change are affecting water availability, consumption and overall sufficiency, particularly in the urban centres. Findings from two Himalayan towns – Murree and Havellian – from Pakistan's Indus Basin area revealed that groundwater is the main source of domestic water, and almost all households are heavily dependent on it. In Murree and Havellian, respectively, springs and municipal water (pumped water) are the sources of groundwater. In both towns, around 35% of households reported that groundwater resources are not sufficient to fulfil their domestic water requirements. Quantitative estimates of water availability, consumption and sufficiency ratio showed consistent results for Havellian, where groundwater is not sufficient to meet the requirements for consumption. However, in the case of Murree, water supplies are sufficient. However, sufficiency ratio based on national standards of water consumption showed that both towns have insufficient water supplies to meet consumption requirements of their respective populations.

In both towns, there is a substantial gap between available water (municipal supply) and actual stored water at household level, indicating the mismanagement issues of water resources at household level. It is also evident from household perception data, which underlined that overexploitation and mismanagement were the key challenges to water sustainability. In addition, one-fifth of surveyed households reported that climate change has also affected the water availability in the towns. Conversely, factors such as rapid urbanization and population growth are likely to result in an increased requirement of water in the future. This will negatively impact the water sufficiency in the study towns.

Based on the findings, the study has suggested the following policy actions:

- Measures are suggested to reduce heavy dependency on and overexploitation of groundwater resources, and to diversify the water sources through tapping the potential of surface water resources.

- Awareness may be created among households as well as water managing authorities to promote judicious use of spring water. The share of spring water to municipal supply needs to be reduced, and surface water to be improved. This will help in protecting the spring sources from depletion.
- There is need to launch an awareness campaign to promote efficient use of water at household level, and to reduce mismanagement and wastage of water. An effective and water value-based pricing mechanism may also be introduced to regulate the water use at household level.
- There is a need to improve town level governance and administration to develop and implement strong regulations regarding urbanization (i.e., town planning and building control), groundwater abstraction and municipal water supply. These regulations may include governance mechanisms for spring water sources and water use rights. The regulations introduced for urbanization may include identification, demarcation and protection of recharge zones for major spring sources. In addition, strong regulatory action is required for setting the criteria and extent of groundwater abstraction at household or community level.

It is hoped that the findings of this study will be useful to understand the situation of water availability, consumption and sufficiency in the Himalayan urban centres of Pakistan, and will provide input to urban planning and implementation of the National Water Policy. The findings and recommendations of this study may also be useful for urban planning in other urban centres of the HKH region, and similar mountain areas from the Global South.

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Supplementary material

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