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Urban environment and sustainable water supply: a comprehensive analysis of Darjeeling city, India

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Abstract
This article is an attempt to analyse the link between the condition of city environment and availability of water in Darjeeling city. Darjeeling, located in the Eastern Himalayan Region of India, is such a city which faces acute water scarcity in most part of the year, except during monsoon. The city cannot use ground water directly, and there is no river as source of water as well. It only uses spring water and rain water. The climatic condition and local environmental conditions have higher control over the availability of daily water. This article analyses the city's 100-year climatic conditions as well as the condition of vegetation cover and built-up areas using NDVI and BUI methods, respectively. The present study explores that the deterioration of natural environmental conditions and increasing demand from both the permanent population and transitory population accelerate the intensity of water scarcity. Measuring the fluctuation of discharge (during pre-monsoon and post-monsoon period), the paper discusses how except in monsoon, most of the spring's discharge gets reduced and increases the level of water stress in the city. Using quantitative methods, this empirical study explores that the loss of vegetation and haphazard constructions have enormous impact on the fragile hill ecosystem and reduce the rate of infiltration of water in the sub-surface zones, thus reducing the discharge ultimately. Therefore, the study recommends immediate actions to protect the city environment and to revive those springs for the city's water security.

Keywords City environment · Water scarcity · Natural springs · Darjeeling

1 Introduction

Water essentially is a part of the natural environment, and a positive environmental condition ensures the availability of water to a great extent. If environmental perspectives are not included within the framework of governance, it makes the way for social disruption following the environmental deterioration. Mountain ecosystems are the sources of many

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natural resources like water, energy, minerals, and forests products, which serve lowland communities. Unsustainable use of these ecological resources poses serious threats to the livelihood of the people directly dependent on those resources (Pandey & Jha, 2012). According to NITI Aayog (2018), the apex planning organisation of India, around 1.5 billion people depend on the Himalayas in terms of water, energy, and food supply. Mountainous regions, having low carrying capacity, are more fragile and sensitive in nature. Carrying capacity is a complex issue and difficult to measure, but ecological limits must be understood to protect the urban Himalaya.[1]

The Indian Himalayan region is one of the largest reserves of fresh water. However, this resource faces high threat, as reported by NITI Aayog in 2018. Climate change has adversely impacted on the functioning of the ecosystems, especially on the water cycle, and several studies have already been completed on this issue in the Himalayan region (Chinnasamy & Prathapar, 2016; Li et al., 2015; Pandey & Jha, 2012; Research and Information System [RIS], 2016; Sharma et al., 2016; Shrestha et al., 2018; Tambe et al., 2012; Vashisht & Sharma, 2007). The case of Darjeeling is not an exception, as almost all the Himalayan cities suffer from acute water crisis. Very recently, the cases of other hill towns such as Shimla and Nainital have come up in the Indian media, showing the severity of water crisis in the urban Himalaya during summer, which is also the peak tourist season. Climate change, especially change in the precipitation pattern, impact of land-use change and urbanisation at the cost of the environment, high tourist flow, increasing water demand and higher water consumption in the luxurious hotels are the prime factors of water crisis in these tourism-based Himalayan cities.[2]

Darjeeling city is essentially dependent on a few springs and rain water, i.e. completely on surface water. Darjeeling experiences high rainfall (around 3104.5 mm per annum), but the people of that particular place continuously face acute water crisis. The crisis of drinking water escalates, especially in the summer season in the city (Planning Commission of India, 2008). Moreover, some site specific environmental factors highly affect the quality of spring discharges. These are water seepage rate which in turn depends on the land-use pattern, nature and degree of disturbance resulting from deforestation and human activities, slope and geology of the catchment area, etc. (Vashisht & Sharma, 2007, p. 839). Therefore, regular monitoring of local environmental conditions is essential to keep the water sources alive. Understanding the importance of 'spring-shed management', the Indian government formed a Working Group on 'Inventory and Revival of Springs of Himalaya for Water Security' in 2017 under NITI Aayog to examine the magnitude of the problems, review existing policies, and execute best possible practices to maintain the flow of water for sustaining both the humans and the environment. Urban morphology alters very fast and modifies overall urban environment these days.

Several studies have been carried out by the researchers such as Vashisht and Sharma (2007), Pandey and Jha (2012), Tambe et al. (2012), Sharma et al. (2016), Chinnasamy and Prathapar (2016), Shrestha et al. (2018) in different parts of the Indian Himalaya, but there is lack of micro-level or city-level research. Darjeeling city's changing environmental and urban morphological condition is not so explored in terms of water scarcity. And here lies the relevance of the study which tries to explore all the possible environmental impacts behind the increasing water crisis. Explaining the present condition of water

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1 https://www.hindustantimes.com/analysis/why-himalayan-towns-are-on-the-brink-of-a-shimla-type-water-crisis/story-4out03d1xblEJJ0BQ1HlfK.html.

2 https://www.downtoearth.org.in/news/water/fragile-blue-mountains-60555.

supply and demand, the article presents a brief description of the physical and climatic conditions of Darjeeling city first and then analyses the continuous decreasing pattern of vegetation cover in and around the city as well as change in the land-use pattern in terms of built-up areas. At the end, it also analyses the conditions of existing springs in terms of its rate of discharge during pre-monsoon and post-monsoon phase of the year, and finally, it concludes with the recommendation that environmental protection is urgent for the city's resilient water future.

2 Materials and methods

This article analyses the basic environmental conditions (areas under vegetation cover and built-up areas), which directly impact the health of the natural springs, and to complete the analysis various kinds of data have been used. Empirical observations and secondary data from different sources are used in this study. The data type is mainly quantitative in nature, but some qualitative data (perception of the local people about the water crisis; key informants' responses, and empirical observation) have also been taken into consideration to compare the result of this study with the actual condition of the city, and to better understand the ground reality. SRTM data have been taken to prepare contour map and elevation map. More than 100 years' climatic data (maximum and minimum temperature and average precipitation) have been plotted in simple scatter diagrams. NDVI, NDBI and BUI are calculated from the Landsat series of satellite images (Landsat MSS—December 24, 1975; Landsat 5-TM—December 23, 1990; Landsat 7-ETM^{+}—December 2005; and Landsat OLI TIRS—January 2, 2018; Row/Path: 41/149).

$$\text{NDVI} = [(\text{NIR} - \text{Red})/(\text{NIR} + \text{Red})]$$

$$\text{NDBI} = [(\text{MIR} - \text{NIR})/(\text{MIR} + \text{NIR})$$

$$\text{BUI} = (\text{NDBI} - \text{NDVI})$$

These images are analysed to prepare the NDVI and BUI maps over the period of 43 years from 1975 to 2018. All the data (Landsat Images) acquisition dates were clear in terms of atmospheric conditions. These images have been acquired from the USGS Earth Resource Observation Systems Data Centre, which produces the images after correcting the radiometric and geometrical distortions. These images are further resampled using the nearest neighbour algorithm with a pixel size of 30×30 m. The images are projected to the Universal Transverse Mercator (UTM) coordinate system.

Moreover, a city-level mapping of springs used for domestic purposes has been done. Discharges of those springs have also been measured to estimate the available spring water during pre-monsoon and post-monsoon season. Previous discharge data of those springs are not available. However, it can be well understood from the narration of the city residents, who are mainly spring water users, that discharge of those springs has deteriorated from that of the past. Ethnographic method has been followed for studying the area in greater detail. To realise the actual ground scenario about the quality of available services, demands of the people, daily sufferings from the crisis, and people's perception and consciousness about socio-environmental impacts, the study used personal interviews (formal and informal) and focus group discussion of the target groups, participant observations, case study, and the oral history methods during field days (Fig. 1).

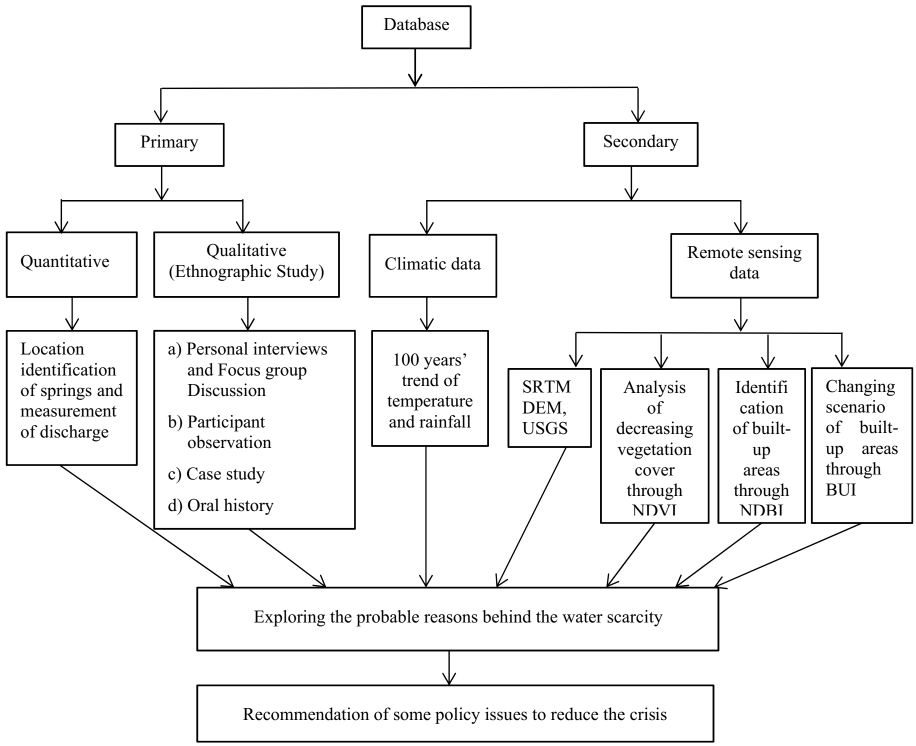


Fig. 1 Methodological framework

3 Study area

Darjeeling is the administrative headquarters and main urban centre of the district. Darjeeling Municipality (established in 1850 by the British government) is one of the oldest municipalities in the country. Presently, the municipality consists of 32 wards with two cantonments (Jalapahar cantonment in the south and Lebong cantonment in the north) within the municipal area. The city is situated on the 'Y' shaped spurs elongated towards the northeast and northwest from the Ghoom range (Dash, 1947). The city is located at 27° 3′ N and 88° 16′ E, covering an area of 13.81 sq. km (Fig. 2).

3.1 Physical condition and availability of surface water

Darjeeling hill region (in the Eastern Himalaya), being a part of the lesser Himalayas, is formed of recent rocks and tectonically unstable as well. The whole region is rich in biodiversity with its unique and picturesque nature (Dash, 1947). The annual mean maximum and minimum temperatures that prevail here are 14.9 °C and 8.9 °C, respectively. The hill receives more than 3000 mm rain per year, yet the city faces acute water crisis during dry season, just like Shillong in Meghalaya, a north-eastern hill state. Geological and lithological characteristics of the hill and heavy monsoon rainfall (maximum from June to September) have a direct impact on landslides and on other natural hazards in the region. The terrain condition is highly rugged with a complex structure of folds and faults (Fig. 3).

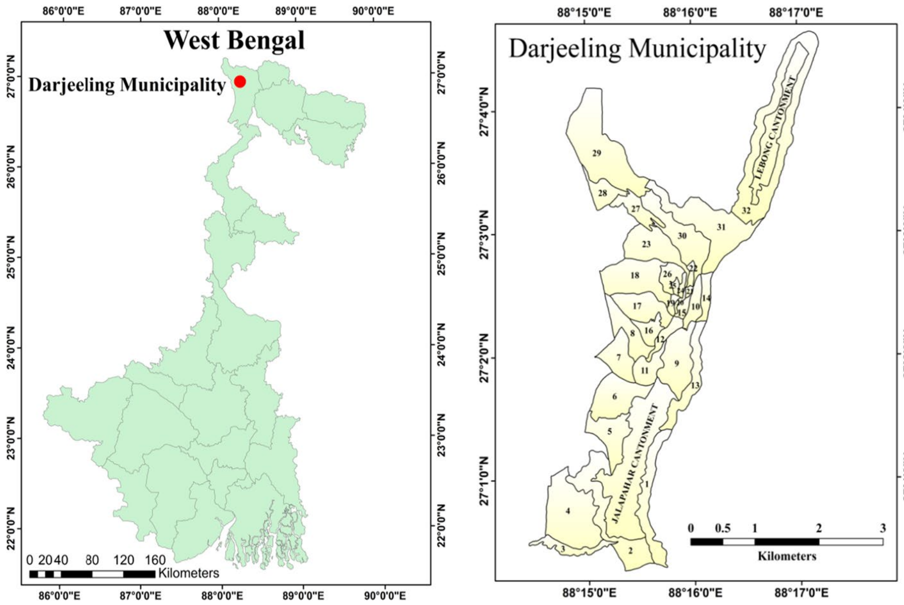
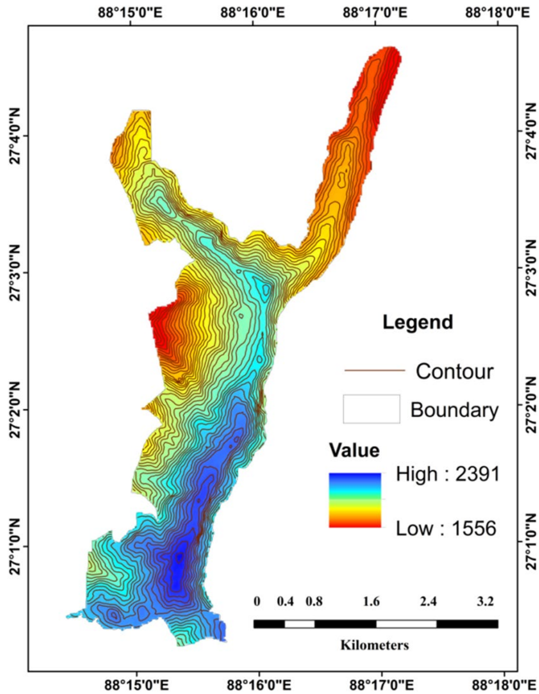


Fig. 2 Location of the study area

Fig. 3 Elevation map of Darjeeling city



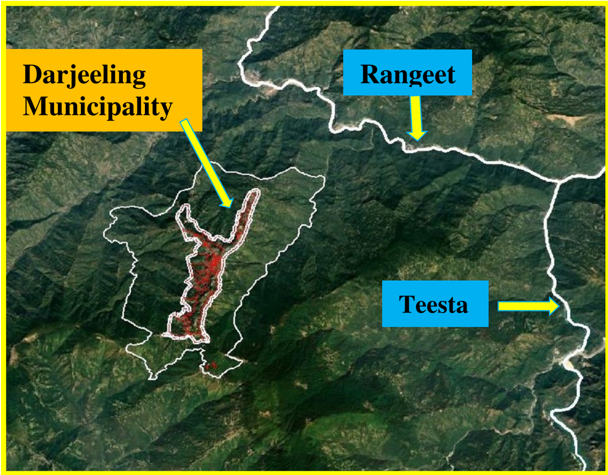


Fig. 4 Rivers around the city

Generally, mountainous regions have some distinctive hydrogeological settings and therefore face acute problems of safe and potable water due to lack of feasible ground water. Himalayan hydrogeology is generally characterised by numerous local aquifers, which feed the innumerable springs of this region. Numbers of rock pores, fissures, fractures, joints, faults and depressions, etc., have been formed by the tectonic activities, and ground water (mainly sub-surface water) comes out from those weak zones of the surface as springs. Although these aquifers are local, often they are recharged from the distant sources, and this happens only due to the structural complexity of rock formation in the Himalayas. Tectonic activities and resultant structural formations primarily control the location of these springs (Choubey et al., 2000, p. 523; Negi & Joshi, 2004; Shah & Kulkarni, 2015, p. 61; Shrestha et al., 2018). 'Therefore, drying up of springs and water scarcity issues underscore the need to increase the understanding of spring hydrology, especially in the Himalayan region' (Chinnasamy & Prathapar, 2016, p. 1).

Mountainous areas are essentially dependent on surface water, such as rivers, streams, springs (jhoras), lakes which are very prone to pollution and deterioration from anthropogenic activities. For example, Nepal is a water-rich country, having more than 6000 rivers, and receives high monsoon rainfall. Despite this, more than a quarter of its 29 million people face acute drinking water crisis as reported by the World View of Global Warming and The Himalayan Times. In case of Darjeeling, although there are a few major and minor rivers located far away from the city (Fig. 4), it is nearly impossible to serve the area using water from these rivers, due to several physical, economic, and technological constraints. An attempt was made by the municipality in 2008 to pump water from the Balasan River to Senchal Lakes (north and south) to meet the increasing water demand of the city. However, the initiative is not fully successful till the day.

3.2 Climatic condition in the last century (1901–2002)

As stated in the previous section, Darjeeling experiences moderate temperature throughout the year except for a few months in winter and receives high rainfall especially

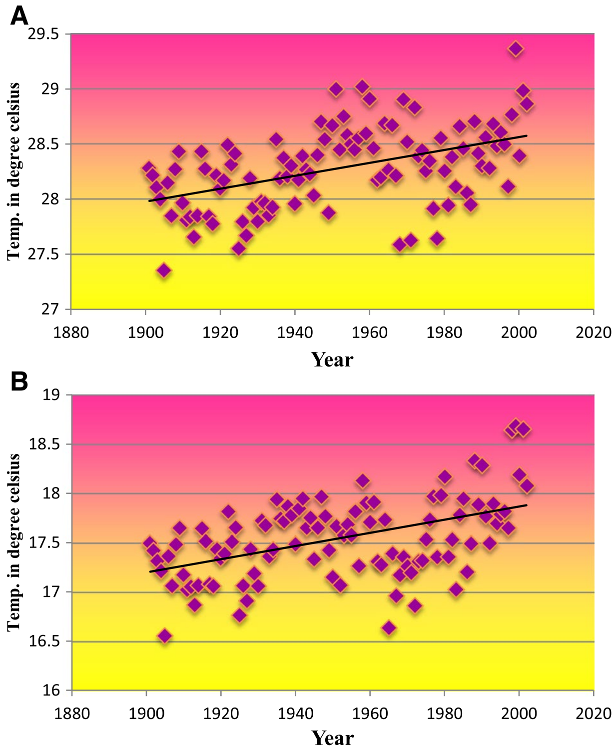


Fig. 5 Trend of temperature from 1901 to 2002 (**a** maximum temperature; **b** minimum temperature)

during monsoon. However, changing trends in temperature and rainfall pattern are traceable here like other parts of the Himalayas. Climate change is not merely a myth; rather, it is the harsh reality of this century. Climate change deeply impacted the water resources of the Himalayan region (Li et al., 2015; RIS, 2016; Tambe et al., 2012; Vashisht & Sharma, 2007). In the present context of climate change, the problem of water scarcity has emerged as the most crucial threat to the human society all over the world. Therefore, to analyse the basic climatic condition of the area, 102-year temperature (maximum and minimum) data are plotted to observe whether any change has occurred or not (Fig. 5).

The above figures show that there is no such big change in the temperature pattern of the hills. However, a slightly increasing trend can be observed in case of both the maximum and minimum temperatures like in other Himalayan cities. This is the most common symptom in the context of climate change. For a long time, urban climate studies have been concerned about measuring the observed ambient air temperature between cities and their surrounding rural areas (Weng et al., 2004). Cities usually have higher impact on the local climate as they generate enormous heat and often turn into heat islands having less vegetative cover. Weng et al. (2004, p. 476) have shown in their study that the unit of land having higher biomass/vegetation abundance has lesser land surface temperature. Therefore, negative correlation is there between vegetation cover and land surface temperature. Urbanisation and related anthropogenic activities usually make the difference between urban Himalayas and rural Himalayas, i.e. hill cities and surrounding rural areas.

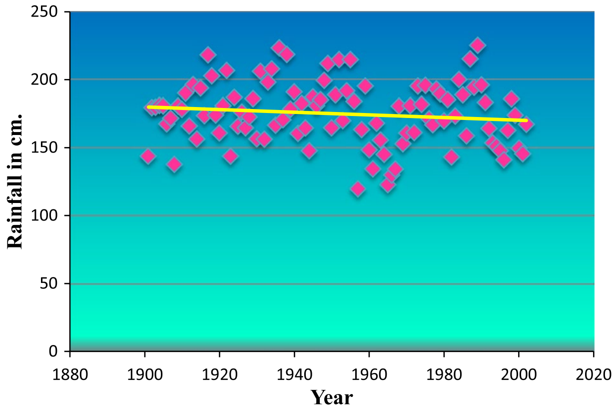


Fig. 6 Rainfall pattern from 1901 to 2002

Darjeeling receives high rainfall mainly during the monsoon (more than 3000 mm per annum), and that replenishes the springs of the hills. Springs are the lifelines of the city as the city is entirely dependent on the springs, located in and around the city. The centralised water supply system of Darjeeling municipality is also dependent on the spring water. Thus, the analysis of rainfall pattern is significant here. To observe the rainfall trend of the city, 102-year rainfall data have been plotted (Fig. 6).

In this case also, no such big change in the rainfall pattern is seen. Figure 6 shows very slight negative change in rainfall. It is also very natural in the context of climate change. However, the obscured reasons behind this small change in air temperature (minimum) and rainfall and its possible environmental impacts are rarely analysed at the micro-level. Thus, context-specific analysis to keep the local environment alive is essential, considering the geo-environmental and social circumstances of that particular area. Before going into detail about the local environmental conditions of Darjeeling city, the following section explains the city's existing water scenario in brief.

3.3 Present context of water crisis in Darjeeling

Darjeeling city's water supply system is entirely controlled by the waterworks department of Darjeeling municipality, and they supply water from the twin lakes, located in the Senchal range (15 km from the city). The twin lakes (Senchal north and south) were built during the British period, one in 1910 and the other in 1932, and after the completion of these lakes, municipal water supply was regular, adequate, and potable. Water has been stored into the lakes after collecting from the surrounding springs in the Senchal areas (Senchal Wild Life Sanctuary). The water storage capacities of these reservoirs were 20 million gallon (MG) and 12.5 MG, respectively, meant to serve only the then population of about 10,000–40,000 people (Darjeeling Municipality, 2012a). Now, the city has a population of over 120,000, who survive on the same source of water (Census of India, 2011). Here, crisis of water primarily reflects on the city's limited capacity to serve the limited number of people. Previously, there was no such water scarcity in Darjeeling, as the population pressure (both permanent and floating) was less. The city was not as commercialised as it is at present. The current water supply is not sufficient for the entire city (Drew & Rai, 2016).

A wide gap exists between the demand and supply of water within the municipal area. Due to many institutional (technical, financial, and political) problems, it is difficult for the municipal authority to cope with the growing demand of water. A water budget of daily demand and supply has been prepared by the waterworks department considering 70 L per capita per day (lpcd) or around 15.5 gallons of water. The estimation shows that the people get water after every four days, due to daily shortage of water. Another estimation of the department shows that people will get water after every seven days, if 135 lpcd of water is to be supplied to them (Darjeeling Municipality, 2012a). These deficits represent the limited capacity of the municipal authority to meet the present demand of the city. However, these estimations only take into account the permanent population. Though as headquarters of the district, a popular hill city, and a reputed educational centre, the city has been experiencing continuous pressure of transitory population for many years. In addition to this, a large number of seasonal labours are engaged in different informal sectors, and they stay in the city for 8–9 months. The municipality and Gorkhaland Territorial Administration (GTA) do not have any estimation about the numbers of seasonal labour. In this regard, Drew and Rai (2018, p. 222) estimated that around 200,000 people constitute the floating population of the city and stay there on a part-time basis. Transitory population are not counted in the city's population size, but these groups of people create pressure on the city's basic infrastructure and services including water. Thus, preparing a water budget or estimating total water demand considering only the permanent population is incomplete (Samanta & Koner, 2016). Moreover, many perennial springs (locally called *Dhara* or *Jhora*) flowed through the city are now dried up. These were the sources of water for thousands of people in the city. In these circumstances, city government is not concerned with the environmental deterioration, thus leading to the further scarcity of water. Next section analyses the continuous changes in the city environment, which are not positive as well as undesirable for the natural water availability.

4 Results and discussion

To explore the city-level environmental change and its certain impact on city life, especially on the availability of spring water, analysis of changing vegetation cover and built-up areas has been done in this section. Besides, the present discharge rate of the existing springs has also been measured. As the city is solely dependent on the surface water, these analyses can better explore the increasing water scarcity from the environmental perspectives.

4.1 Analysis of decreasing vegetation cover

Vegetation is one of the major components of a terrestrial ecosystem, which directly influences the living organisms. Vegetation cover plays an important role in the functioning of various natural and man-made systems. It also determines the environmental condition of a region to a large extent. Continuous monitoring of vegetation cover is necessary to understand different systems and also for managing natural resources (Roy et al., 2013). Urban areas represent the conflict zones between development and environment, where different types of environmental problems can be found due to human-induced developmental activities (Van de Voorde et al., 2008). Environmental problems deteriorate the quality of city life, which shows the negative side of urbanisation at the cost of environment. Sufficient vegetation cover in and around the urban areas has a positive impact on the city environment, as it improves the air quality, increases the water infiltration rate, and minimises the urban heat island effect (Van de Voorde et al., 2008). Changes in vegetation cover have a direct influence on climatic characteristics (Lean & Warilow, 1989). Accurate estimation of vegetation cover helps to assess the environmental condition in a better way, which is also essential for taking protection and restoration measures (Myers et al., 2000; Roy et. al., 2015).

Traditional methods of vegetation mapping like field surveys, map interpretation, and ancillary data analysis are time-consuming and expensive, whereas remote sensing data provide updated information and also save time and money (Joshi et al., 2006; Navalgund et al., 2007; Townshend et al., 1991). Changes in the vegetation cover can be easily identified through an analysis of satellite images, as the extensive data archive helps to extract historical information as well (Lillesand, 2008). The Landsat series of satellite has the longest history of monitoring the earth and provides continuous data from 1972. Landsat images have been widely used for different purposes due to its continuous recording of the global land surface and rich data repository (Xie et al., 2008).

Different types of vegetation indices, which are based on the remotely sensed data, have been used for mapping the vegetation cover (Lambert et al., 2013). The Normalized Difference Vegetation Index (NDVI) is the most commonly and widely used vegetation index for monitoring the vegetation cover (Bhandari et al., 2012; Gandhi et al., 2015; Ke et al., 2015). NDVI is a ratio difference between canopy reflectance in the red and infrared bands [(NIR − Red)/(NIR + Red)] (Rouse et al., 1974; Townshend & Justice, 1986). The main principle behind NDVI is that reflection from vegetation is high in the near-infrared band, whereas absorption is high in the red band (Tucker, 1979). The contrast between these two indicates the status of vegetation (Xie et al., 2008). NDVI is performed on a pixel-by-pixel basis, where the algorithm subtracts the value of red band from the value of near-infrared band and divides by their sum (Townshend et al., 1985). Values of NDVI vary from −1 to +1, where negative value represents water bodies; very low positive value refers to barren rocks, sands or snow; moderate values indicate shrub and grassland; and high values correspond to forest land (Hu et al., 2008). High NDVI value refers to a high degree of greenness and therefore is a good indicator of dynamic changes of vegetation (Wang & Tenhunen, 2004).

Four successive Landsat images (from the years 1975, 1990, 2005, and 2018) were analysed to identify the existing scenario of vegetation cover and the rate of decrease over time. Deforestation has direct impact on the rate of water infiltration (Van de Voorde et al., 2008). In a fragile mountainous environment, vegetation cover plays a vital role in determining the environmental quality as well as maintaining its sustainability. The rate of runoff increases with the decrease in vegetation cover and decelerates the amount of water seepage. Moreover, loss of trees decelerates the water holding capacity of the landscape (Negi & Joshi, 1996; NITI Aayog, 2018), and by this way it controls the storage of subsurface water. And both the rate of water seepage and condition of sub-surface water determine the rate of spring-water discharge, as all the springs in and around Darjeeling city are fed by sub-surface water.

4.1.1 Deforestation around the city (1975–2018)

Longitudinal analysis of deforestation within the municipal boundary alone cannot explore the nature of problem, because springs often have their recharge areas far from their sources. Around the city, a larger area is demarcated following the valleys, including the Senchal lake areas (Fig. 7). Deforestation in this extensive area has great impact on the water availability of the city. As reported by Darjeeling municipality (2012a), deforestation

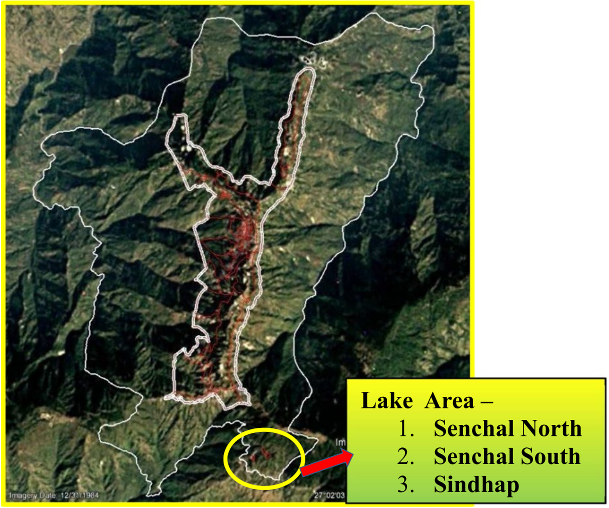


Fig. 7 The city and the demarcated surrounding area

Table 1 Decreasing vegetation cover surrounding the city

Year	Area under vegetation cover (%)
1975	88.36
1990	75.93
2005	70.22
2018	55.60

has decreased the water storage in the lakes and consequently has reduced the municipal supply. Deforestation thus directly helps to increase run-off, reduce infiltration, and consequently lower the water availability from the springs. Therefore, long-term analysis of vegetation conditions of the surrounding area has certain relevance.

Image analysis clearly shows that the area has been experiencing continuous deforestation over a long period of time. In 1975, more than 88% area was under the vegetation cover, which was quite normal for the mountainous tract. With the population growth and initiation of so-called developments, forest cover has decreased steadily and presently, only 55% of the total area has vegetation cover. Interestingly, the rate of deforestation has been higher in two phases: one during the period of 1975–1990 and another during 2005–2018 (Table 1). The first phase experienced high rate of deforestation, probably because of the violent Gorkhaland movement. This is also evident from the words of many of the elderly key informants. During field work, they talked about the devastating tree cutting and man-made forest fires during that time of the movement. The second phase of high deforestation (2005–2018) has occurred mainly due to the rapid urban growth and construction activities.

The maps (Fig. 8) show the steady decrease of vegetation mainly in the western part of the region and also in the area surrounding the Senchal range, where the lakes are situated. Deforestation mainly around the Senchal areas surely affects the city's water supply, because the central water supply system depends on the springs in the Senchal

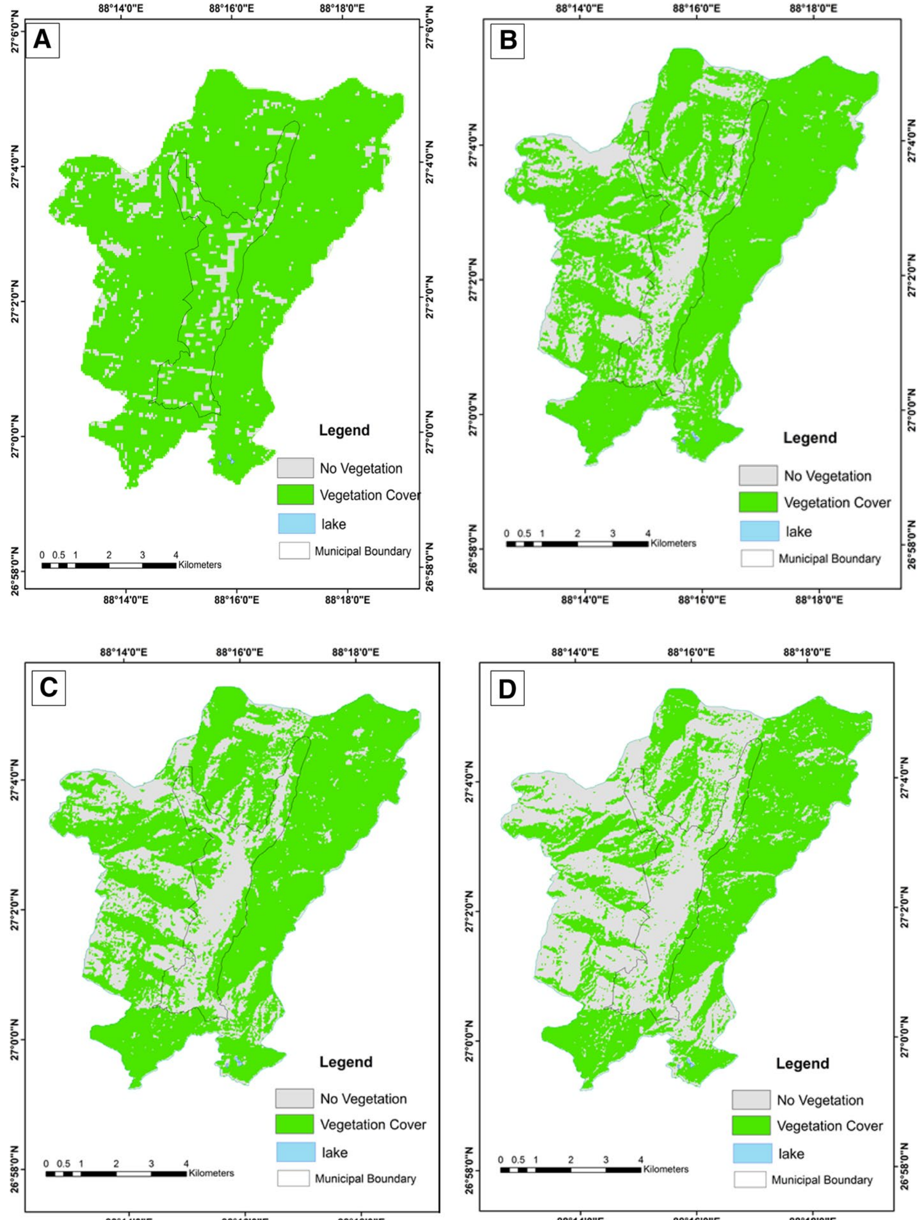


Fig. 8 Normalized Difference Vegetation Index (NDVI) of surrounding areas of Darjeeling city from 1975 to 2018 (**a** 1975; **b** 1990; **c** 2005; **d** 2018)

range. Previously, the number of springs was higher but now, due to high deforestation in the catchment areas of the springs, many springs along the *Senchal* range have dried up. The number of springs has decreased from 26 to 11 at present, from where water

Table 2 Decreasing vegetation cover within the city

Year	Area under vegetation cover (%)
1975	72.81
1990	65.07
2005	53.46
2018	42.58

comes throughout the year (Darjeeling Municipality, 2012a). Further, the private water supply also depends completely on the springs outside the city. Loss of vegetation cover is the main reason behind the drying up of these springs. Thus, the vegetation cover surrounding the city impacts the city's water availability significantly.

4.1.2 Deforestation within the municipal area (1975–2018)

The same scenario is observed within the municipal area, from 1975 till date. But interestingly, here the rate of deforestation was higher during 1990–2005 (Table 2). The probable reasons for the higher level of deforestation in that phase were the population growth and stable political situation. During that time, decadal growth of population in the city was highest (46.72) leading to a faster process of urbanisation. Population density is very high in Darjeeling, which does not match with the fragile environment of a hill city. Construction of concrete houses, commercial buildings, multi-storied apartments and shopping complexes, all took place at the cost of the vegetation cover.

From these maps (Fig. 9), it is estimated that at present, only 42% land is under the vegetation cover. This has been impacting the rate of water seepage and ultimately the spring discharge. Many springs have dried up due to construction activities in the catchment areas. Six such spots, where springs used to flow just a few years ago, have been pointed out by the local residents during the informal interviews in the city. Therefore, like other Himalayan cities, Darjeeling is also suffering from increasing water stress due to environmental changes through deforestation, and other types of anthropogenic activities, like uncontrolled construction works.

4.2 Built-up area index (BUI)

Land-cover changes drastically over a shorter time span, particularly in case of urban areas (Zha et al., 2003). Ever-increasing population density and unplanned urban growth create enormous pressure over the resources in the urban areas (Bugliarello, 2003). On the one hand, urbanisation indicates economic development, but, on the other hand, it also reflects the degraded environmental condition of the city (Barnes et al., 2001). Generally in most cases, the urban sprawl takes place at the cost of greenery, which puts the sustainability of the local communities at risk (Bhatta et al., 2010). It is an uphill task for city planners to manage the available resources in a better way. Successful city planning and resource management depends upon understanding the spatio-temporal distribution of urban areas (Bertrand-Krajewski et al., 2000). Accurate mapping of the built-up areas is a basic task for this purpose. Satellite remote sensing data provide useful information about the spatial distribution and growth of the built-up areas (Bhatta, 2009; Griffiths et al., 2010; Guindon

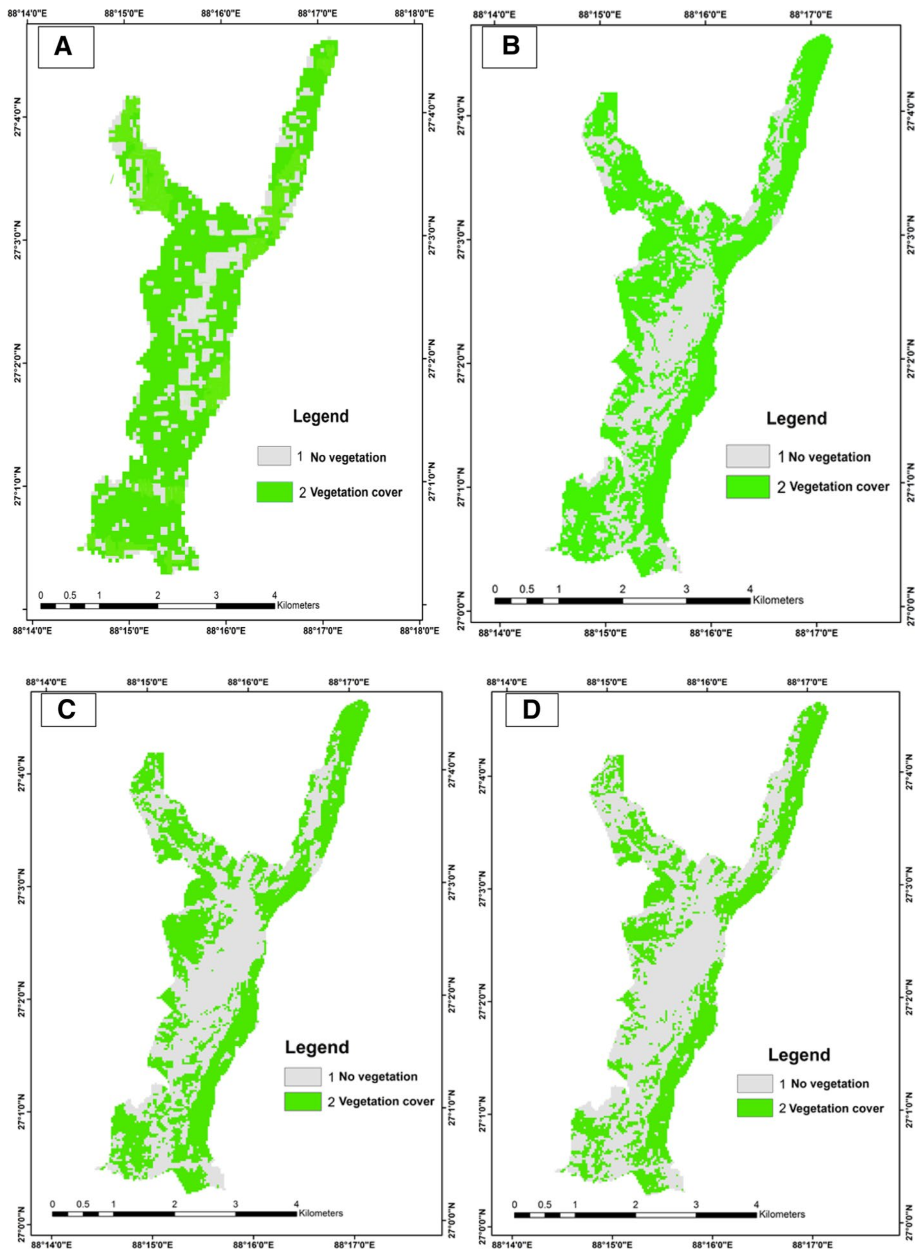


Fig.9 Normalized Difference Vegetation Index (NDVI) of Darjeeling city from 1975 to 2018 (**a** 1975; **b** 1990; **c** 2005; **d** 2018)

et al., 2004). Historical archives help to understand the spatio-temporal growth in an easier way than conventional survey methods (Maktav et al., 2005; Richards, 2013).

Remote sensing data have been used in several studies for mapping the built-up areas (Jensen, 2006; Lillesand et al., 2008). Automatic mapping of the urban built-up areas

Table 3 Increasing built-up area

Year	Built-up area (%)
1990	31.34
2005	41.11
2018	54.29

through indices provides more accurate results in comparison with pixel-based or object-based classification (Bhatti & Tripathi, 2014). The Normalized Difference Built-up Index (NDBI) was developed by Zha et al. (2003) for mapping the built-up areas automatically. They have used the ratio difference of near-infrared (NIR) and mid-infrared (MIR) bands of Landsat Thematic Mapper (TM) to create NDBI [(MIR − NIR)/(MIR + NIR)]. In the case of built-up areas, reflection is high in the mid-infrared band, whereas it is low in the near-infrared band (Bhatti & Tripathi, 2014). Zha et al. (2003) also recoded the existing NDVI and NDBI with binary numbers, where positive values were assigned a new value of 254 and the negative values were assigned 0. Then, the recoded NDVI image was subtracted from the recoded NDBI image, and the resulting pixels with positive values were categorised as built-up area. Then, they used further steps to eliminate the vegetation noise from the actual built-up area.

The refinement approach of Zha et al. (2003) was, however, unable to differentiate the barren and bare land from the built-up area, because the binary recoding process only shows the value of 0, −254 and + 254 in the final output (Bhatti & Tripathi, 2014). He et al. (2010) proposed a modified version to overcome the shortcomings of the earlier approach. Instead of using binary recoded images, they have used continuous NDBI and NDVI images. The subtracted output image was also a continuous image, where the built-up area was extracted from positive values by using a threshold. This modified approach (He et al., 2010) is used in this study to identify the built-up areas for 1990, 2005 and 2018. Threshold values have been assigned through the manual trial and error procedure. Determination of the threshold through long trial and subsequent empirical observation improves the quality of the resulted output (Chen et al., 2003). Output maps were verified through the field survey to increase the accuracy of the result.

4.2.1 Concretisation in the city (1990–2018)

Analysis of the three Landsat images from the years 1990, 2005, and 2018 shows the steady growth of concretisation over this period of time. It is a common trend for all cities that with the population growth and commercialisation, construction activities increases, which negatively impact the city environment. In the previous section, the trend of deforestation within the city has been analysed, which supports the increasing trend of built-up area. After the 1990s population hike, the city experienced accelerated construction at the cost of green environment. These days, more than 54% of the total area belongs to built-up area (Table 3).

The above maps (Fig. 10) show the steady growth of construction activities within the city, starting from its central part towards the periphery. Similarly, Fig. 11 clearly visualises the city's change in settlement density over time. Construction activity reduces the lifespan of natural springs and hence leads to water scarcity. Therefore, exploring the present status of the springs is essential for understanding the city's water future.

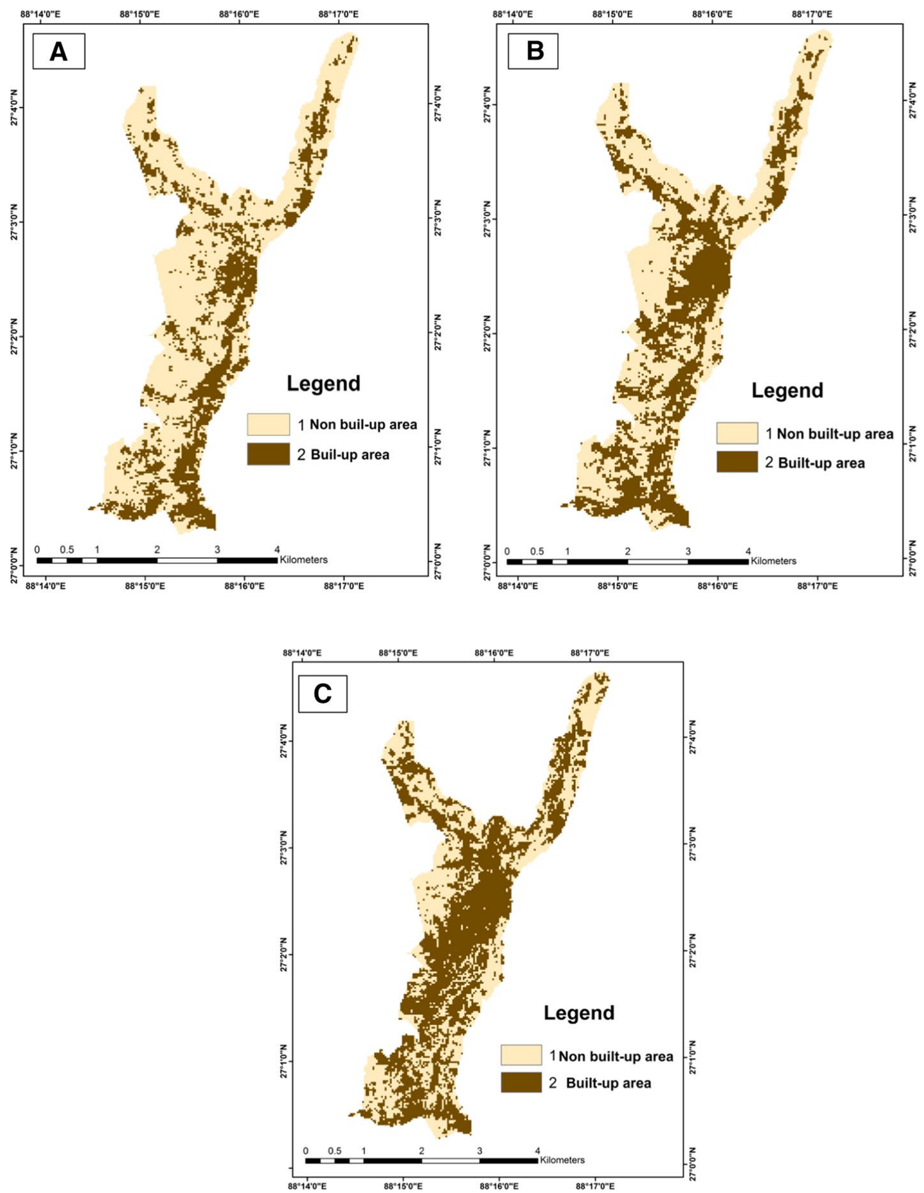


Fig. 10 Built-up area index (BUI) of Darjeeling city from 1990 to 2018 (**a** 1990; **b** 2005; **c** 2018)

Presently, Darjeeling faces a range of political, economic, and environmental crises (Shneiderman & Middleton, 2018, p. 2). These have significant impacts on the city's overall socio-economic circumstances, and environmental conditions in particular. With a mountainous physiography, the city had been endowed with innumerable natural springs, which could satisfy the needs of the people. These were the only source of water before the construction of the twin lakes by the British in the first half of the twentieth century.

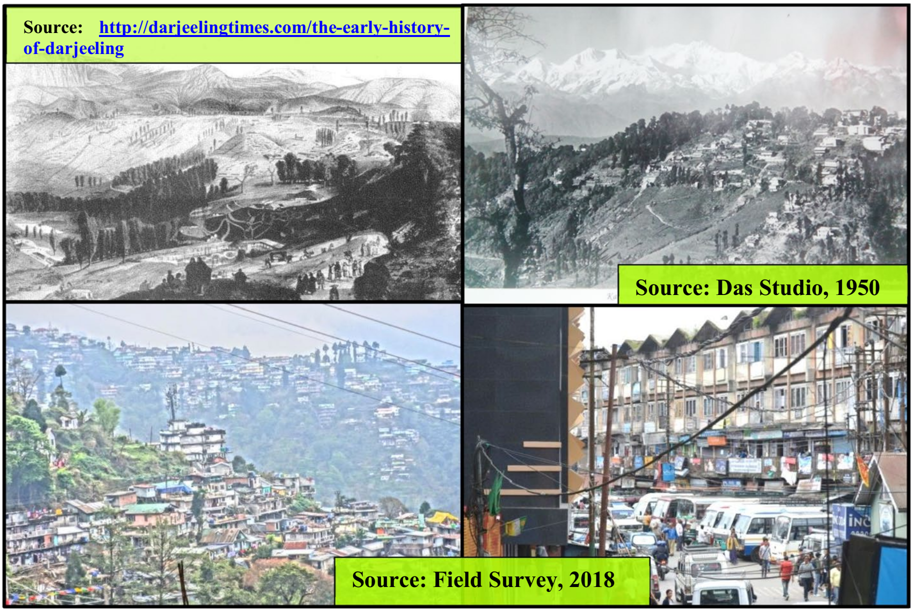


Fig. 11 City's change over time

With the steady population growth over time, this system became insufficient in comparison with demand, and the city became water stressed. Therefore, assessment of the existing springs' health is required to explore the water supply capacity of the springs, and that has been done by estimating the discharges during two phases of the year, i.e. one in pre-monsoon and other in post-monsoon period.

4.3 Natural prospects of spring water in the city

Springs are the main source of water (especially water for domestic uses) for thousands of people, living in the Himalayan region, and unfortunately, these are in threat from the impact of climate change, land-use land-cover change, and other kinds of anthropogenic activities (Chinnasamy & Prathapar, 2016; Sharma et al., 2016; Shrestha et al., 2018; Tambe et al., 2012; Vashisht & Sharma, 2007).

As mentioned earlier, a number of springs in Darjeeling city have dried up, and the existing ones have deteriorated in terms of discharge and perennial flow. The role of the anthropogenic activities has been described in the previous sections. Therefore, one assessment of the existing springs and their capacity to serve the people within the city has been done. Around 24 springs have been identified and plotted on the city map (Fig. 12), from where people collect water for their domestic needs.

After measuring the rate of flow (minutes/10 L), these springs have been categorised into four (pre-monsoon) and three (post-monsoon) types (Tables 4 and 5). Data have been collected during two time periods of the year—one in pre-monsoon (driest period) and the other in post-monsoon season (wettest period) to better understand the seasonal variation of water availability. The highest availability of water during and after monsoon season is

Fig. 12 Location of springs within the city

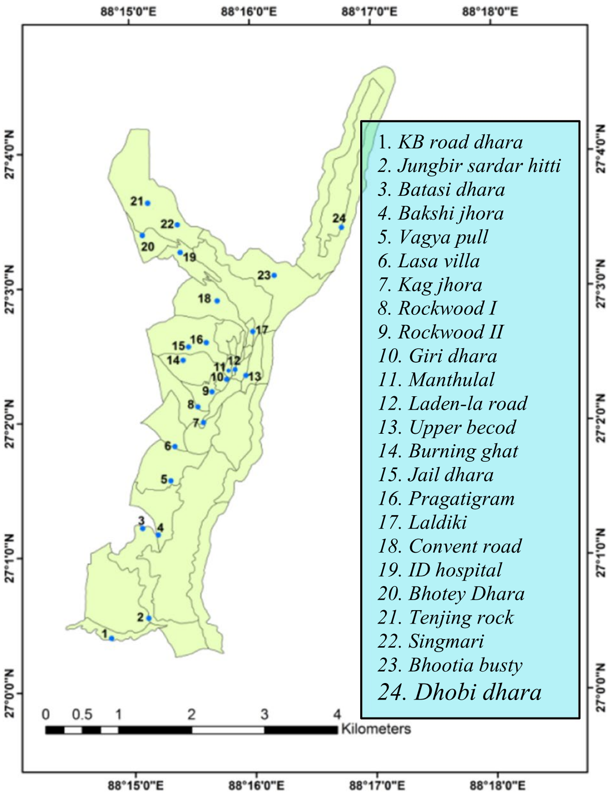


Table 4 Spring discharge during pre-monsoon. *Source*: Field data, 2–3 June 2018

Time (min)/10 lit.water	No. of springs	Total water/day (average in lit.)
0.6–3	6	86,400
3–6	11	39,600
6–9	5	10,000
9–13	2	2707.9
Total	24	138,707.9

Table 5 Spring discharge during post-monsoon. *Source*: Field data, 23–24 September 2016

Time (min)/10 lit.water	No of springs	Total water/day (average, lit.)
0.1–1	16	1,267,200
1–2	6	64,800
2–3	2	12,000
Total	24	1,344,000

a very common feature for the region, which receives plenty of monsoon rain, and Darjeeling is the perfect example of that.

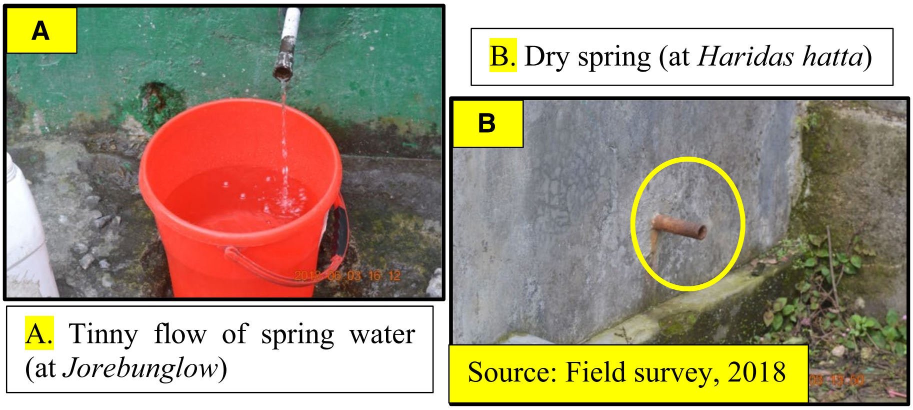


Fig. 13 Condition of the springs during dry season

From the above estimate during the driest phase of the year, majority of the springs fall under the second category; that is, the required time varies from 3 to 6 min for 10 L of water, and only 6 springs come under the first category, which take 0.6–3 min for 10 L of water. Total amount of discharged water per day is around 138,708 L, which can serve almost 1387 households, if 100 L of water is distributed to each household. During the dry season, not only does the discharge of water decrease (Fig. 13), but because of that the time taken to collect water per day also increases. This impacts the livelihood of the people, who are completely spring water users. However, the situation is reversed during the monsoon and post-monsoon season, up to December.

Here, in the above table, estimation has been made for the post-monsoon season when water is abundant and discharge is much higher than the pre-monsoon period. During this time period, highest numbers of springs fall under the first category, which take very less time, i.e. 0.1–1 min per 10 L of water. People do not have to wait much at the spring site to collect the required amount of water for their households. During this time, if water can be stored and distributed at the rate of about 100 L per household, around 13,440 households can be served. Moreover, during the monsoon all the households use rainwater according to their requirements and capacity. Therefore, as people get abundant water, during this phase the municipality can store the excess water to use later.

5 Policy and managerial implications

Considering the socio-environmental circumstances, the article focuses on the following micro-level policy issues, which can reduce the existing water stress of the city. Small-scale and less cost-intensive planning is required for supply system such as increasing storage capacity through new lakes and tanks; renovation of twin lakes (Senchal N and S); regular maintenance of the age old pipelines to reduce water loss through leakages; making more subsidiary tanks to serve every parts of the city; and storage of excess spring water during monsoon to use it during dry season. Besides, distribution of water only by gravity cannot serve all the areas. Therefore, small pumping stations are required in a well-distributed manner throughout the city. To better understand the actual gap between demand and supply, all sections of transitory population (residential students, seasonal labourers, and tourists) must be included while preparing the municipal water budget. That will certainly accelerate the proper water management process. Moreover, water authority must know the actual number of hotels in the city, which can further help in identifying actual water requirement during peak tourist season. And use of water meters is essential, especially for supplying water to the hotels.

In case of environmental factors, to revive and maintain the flow of the springs, illegal constructions around the spring sources must be stopped. City administration should be very cautious about the loss of vegetation in and around the city. There must be a well-planned spring-shed management system, where both the local communities and public authority can participate. Such kind of joint management strategy is a collective action by the city government, other stakeholders, and users. Following Whyte (1986), it can be said that the system will run with the aim of increasing efficiency, equity, cost recovery, and extension of service coverage to poor communities. Active participation of the locals increases the probability of success of any local developmental project. It is essential in order to serve all groups, especially the poor and other disadvantaged groups equally and in joint management programme, members from all the social groups and classes within a community participate and cooperate with each other in making the project a successful one. This type of initiative helps to raise the voice of the locals and will address the issue of social justice through the water justice.

6 Conclusion

'Across the world, global warming, coupled with deforestation of mountain woodlands, mining, agriculture, and urban sprawl in mountain watersheds, threaten water supplies for more than half the world's people' (Johnston, 2008, p. 75). Pandey and Jha (2012) stated that the globalised world threatens the human–mountain relations and this outlines the issues of global sustainability. Natural scarcity of water is purely linked to the global as well as local environmental conditions. Many longitudinal and intensive studies have been completed to examine the spring's health and their relation with local environmental conditions by different institutions and scholars such as Negi and Joshi (1996); Vashisht and Sharma (2007); Tambe et al. (2012); Sharma et al. (2016); Chinnasamy and Prathapar (2016); and Shrestha et al. (2018), etc., where they have revealed that discharges of the springs do not remain same throughout the year. It fluctuates with the amount of rainfall received in the catchment areas or recharge areas of the springs. Besides, deforestation is another important reason behind the drying up of springs. Improvement in vegetation cover will increase the life span of the springs as well as will enhance the rate of spring discharge (Negi & Joshi, 1996).

Analysing the overall condition of the city environment, which directly affects the water availability of Darjeeling city, it can be said that the random constructions on or near the catchment areas of the springs and uncontrolled cutting of trees must be stopped as both have direct impacts on the water seepage as well as water discharge. Along with these, the Urban Local Body (ULB) must take steps to control the haphazard dumping of solid waste (Fig. 14). Unmanaged solid wastes also hinder the seepage and enhance the chances of contamination. Besides, many springs are not usable these days due to direct outlet of liquid wastes into the springs (Darjeeling Municipality, 2012b). Therefore, waste management is essential to maintain the flow of the springs.

Fig. 14 Solid waste dumping

During monsoon, discharge of springs remains almost 10 times higher than that of dry season. During monsoon, all households use rainwater. At that time users just go to the spring to collect water, mainly for drinking and cooking. Thus, excess water can be stored in small subsidiary tanks in different parts of the city and supplied when it is needed. All cannot be served by this, but many can get easy and equal access, which in turn makes the way for water justice. To increase that access equally, the role of public management of water or water governance is important.

Scott (1998, quoted in Bakker, 2007, p. 432) has stated, 'Some research also suggests that states can rationally administer environmental degradation and resource appropriation from local communities'. The concept of 'urban sustainability fix' can be borrowed here, while discussing the responsibility of the local government. This has been used in the debate of Urban Political Ecology (UPE) by David Gibbs, Andrew Jonas and Aidan While, based on David Harvey's concepts of 'Spatial Fixes'. Here, they argued that 'historically contingent notion of a "sustainability fix" is intended to capture some of the governance dilemmas, compromises, and opportunities created by the current era of state restructuring and ecological modernization' (quoted in Keil, 2005, p. 645). This becomes a powerful tool in UPE and is well accepted by the academicians and policy makers, because it does not deny the issues of growth for preserving ecological balance. Rather, it encourages the growth considering some ecological goals in the greening of urban governance (Keil, 2005). Here also, development at the cost of environment must be stopped to make alive the city with its natural resources. Environmental management is crucial to make the city's water future sustainable and resilient.

References

Bakker, K. (2007). The "commons" versus the "commodity": Alter-globalization, anti-privatization and the human right to water in the global south. *Antipode, 39*(3), 430–449.
Barnes, K. B., Morgan, J. M., III., Roberge, M. C., & Lowe, S. (2001). *Sprawl development: Its patterns, consequences, and measurement*. (pp. 1–24). Towson University.
Bertrand-Krajewski, J. L., Barraud, S., & Chocat, B. (2000). Need for improved methodologies and measurements for sustainable management of urban water systems. *Environmental Impact Assessment Review, 20*(3), 323–331.
Bhandari, A. K., Kumar, A., & Singh, G. K. (2012). Feature extraction using normalized difference vegetation index (NDVI): A case study of Jabalpur city. *Procedia Technology, 6*, 612–621.
Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: A case study of Kolkata, India. *International Journal of Remote Sensing, 30*(18), 4733–4746.
Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography, 30*(4), 731–740.
Bhatti, S. S., & Tripathi, N. K. (2014). Built-up area extraction using landsat 8 OLI imagery. *GIScience & Remote Sensing, 51*(4), 445–467.
Bugliarello, G. (2003). Large urban concentrations: A new phenomenon. In G. Heiken, R. Fakundiny, & J. Sutter (Eds.), *Earth science in the city: A reader.* (pp. 7–19). American Geophysical Union.
Census of India. (2011). *Primary census abstract. Darjeeling district*. New Delhi: Government of India.
Central Public health and Environmental Engineering Organization (CPHEEO). (2005). *Status of water supply, sanitation and solid waste management in urban areas*. Ministry of Urban Development. Government of India.
Chen, J., Gong, P., He, C., Pu, R., & Shi, P. (2003). Land-use/land-cover change detection using improved change-vector analysis. *Photogrammetric Engineering & Remote Sensing, 69*(4), 369–379.
Chinnasamy, P.; Prathapar, S. A. (2016). *Methods to investigate the hydrology of the Himalayan springs: A review*. International water management institute (IWMI). IWMI Working Paper (169), pp. 1–15.
Choubey, V. M., Bartarya, Sk., & Ramola, R. C. (2000). Radon in Himalayan springs: A geohydrological control. *Environmental Geology, 39*(6), 523–530.
Dash, A. J. (1947). *Bengal district gazetteer: Darjeeling*. N.L. Publishers.
Drew, G., & Rai, R. P. (2016). Water management in post-colonial Darjeeling: The promise and limits of decentralised resource provision. *Asian Studies Review, 40*(3), 321–339.
Drew, G., & Rai, R. P. (2018). Connection amidst disconnection: Water struggle, social structures, and geographies of exclusion in Darjeeling. In T. Middleton & S. Shneiderman (Eds.), *Darjeeling reconsidered.* (pp. 219–239). Oxford University Press.
Gandhi, G. M., Parthiban, S., Thummalu, N., & Christy, A. (2015). NDVI: Vegetation change detection using remote sensing and GIS—a case study of Vellore district. *Procedia Computer Science, 57*, 1199–1210.
Griffiths, P., Hostert, P., Gruebner, O., & van der Linden, S. (2010). Mapping megacity growth with multi-sensor data. *Remote Sensing of Environment, 114*(2), 426–439.
Guindon, B., Zhang, Y., & Dillabaugh, C. (2004). Landsat urban mapping based on a combined spectral–spatial methodology. *Remote Sensing of Environment, 92*(2), 218–232.
He, C., Shi, P., Xie, D., & Zhao, Y. (2010). Improving the normalized difference built-up index to map urban built-up areas using a semiautomatic segmentation approach. *Remote Sensing Letters, 1*(4), 213–221.
Hu, Y., Ban, Y., Zhang, Q., Zhang, X., Liu, J., & Zhuang, D. (2008). Spatial: Temporal pattern of GIMMS NDVI and its dynamics in Mongolian Plateau. In *IEEE Proceeding on international workshop on earth observation and remote sensing applications.* pp. 1–6.
Jensen, J. R. (2006). *Remote sensing of the environment: An earth resource perspective*. Prentice Hall.
Johnston, B. R. (2008). The political ecology of water: An introduction. *Capitalism Nature Socialism, 14*(3), 73–90.
Joshi, P. K., Roy, P. S., Singh, S., Agrawal, S., & Yadav, D. (2006). Vegetation cover mapping in India using multi-temporal IRS wide field sensor (WiFS) data. *Remote Sensing of Environment, 103*(2), 190–202.
Ke, Y., Im, J., Lee, J., Gong, H., & Ryu, Y. (2015). Characteristics of Landsat 8 OLI-derived NDVI by comparison with multiple satellite sensors and in-situ observations. *Remote Sensing of Environment, 164*, 298–313.
Keil, R. (2005). Progress report: Urban political ecology. *Urban Geography, 26*(7), 640–651.
Lambert, J., Drenou, C., Denux, J. P., Balent, G., & Cheret, V. (2013). Monitoring forest decline through remote sensing time series analysis. *GIScience & Remote Sensing, 50*(4), 437–457.
Lean, J., & Warrilow, D. A. (1989). Simulation of the regional climatic impact of amazon deforestation. *Nature, 342*, 411–413.

Li, H., Xu, C. Y., Beldring, S., Tallaksen, L. M., & Jain, S. K. (2015). *Water resources under climate change in Himalayan basins*. Springer.

Lillesand, M. T., KIefer, W. R., Chipman, N. J. (2008). *Remote sensing and image interpretation*. (3rd ed.). Wiley.

Maktav, D., Erbek, F. S., & Jürgens, C. (2005). Remote sensing of urban areas. *International Journal of Remote Sensing, 26*(4), 655–659.

Darjeeling Municipality. (2012a). Project report of waterworks department.

Darjeeling Municipality. (2012b). Project report of conservancy department.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853–858.

Navalgund, R. R., Jayaraman, V., & Roy, P. S. (2007). Remote sensing applications: An overview. *Current Science, 93*(12), 1747–1766.

Negi, G. C. S., & Joshi, V. (1996). Geohydrology of springs in a mountain watershed: The need for problem solving research. *Current Science, 71*(10), 772–776.

Negi, G. C. S., & Joshi, V. (2004). Rainfall and spring discharge patterns in two small drainage catchments in the Western Himalayan mountains, India. *The Environmentalist, 24*, 19–28.

NITI Aayog. (2018). *Inventory and revival of springs in the himalayas for water security*. Report of Working Group 1.Government of India.

Pandey, R., & Jha, S. (2012). Climate vulnerability index-measure of climate change vulnerability to communities: A case of rural lower Himalaya, India. *Mitigation and Adaptation Strategies for Global Change, 17*(5), 487–506.

Planning Commission of India. (2008). *Problems of hilly habitations in areas covered by Hill Areas Development Program (HADP)/Western Ghats Development Program (WGDP)*. Retrieved from http://planningcommission.nic.in/aboutus/committee/wrkgrp11/tg11_hillarea.pdf.

Research and Information System (RIS) for Developing Countries. (2016). *India and sustainable development goals: The way forward*. United Nations.

Richards, J. A. (2013). *Remote sensing digital image analysis: An introduction*. Springer.

Rouse Jr, J., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the great plains with ERTS. In *Proceedings of the 3rd ERTS Symposium*, NASA SP-351, pp. 309–317.

Roy, P. S., Behera, M. D., Murthy, M. S. R., Roy, A., Singh, S., Kushwaha, S. P. S., & Gupta, S. (2015). New vegetation type map of India prepared using satellite remote sensing: Comparison with global vegetation maps and utilities. *International Journal of Applied Earth Observation and Geoinformation, 39*, 142–159.

Roy, P. S., Murthy, M. S. R., Roy, A., Kushwaha, S. P. S., Singh, S., Jha, C. S., & Saran, S. (2013). Forest fragmentation in India. *Current Science, 105*(6), 774–780.

Samanta, G., & Koner, K. (2016). Urban political ecology of water in Darjeeling. *India South Asian Water Studies, 5*(3), 42–57.

Scott, J. C. (1998). *Seeing like a state: How certain schemes to improve the human condition have failed*. Yale University Press.

Shah, M., & Kulkarni, H. (2015). Urban water systems in India: Typologies and hypothesis. *Economic and Political Weekly, 30*, 57–69.

Sharma, B; Nepal, S; Gyawali, D; Pokharel, GS; Wahid, SM; Mukherji, A; Acharya, S; Shrestha, AB. (2016). *Springs, storage towers, and water conservation in the midhills of Nepal.* Nepal Water Conservation Foundation and International Center for Mountain Development (ICIMOD), Working Paper 2016/3, pp. 1–45.

Shneiderman, S., & Middleton, T. (2018). Introduction: Darjeeling reconsidered. In T. Middleton & S. Shneiderman (Eds.), *Darjeeling reconsidered: Histories, politics, environments.* Oxford University Press.

Shrestha, R. B., Desai, J., Mukherji, A., Dhakal, M., Kulkarni, H., Mahamuni, K., Bhuchar, S., & Bajracharya, S. (2018). *Protocol for reviving springs in the Hindu Kush Himalayas: A practitioner's manual*. (pp. 1–73). International Centre for Integrated Mountain Development (ICIMOD).

Tambe, S., Kharel, G., Arrawatia, M. L., Kulkarni, H., Mahamuni, K., & Ganeriwala, A. K. (2012). Reviving dying springs: Climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development. International Mountain Society, 32*(1), 62–72.

Townshend, J. R., Goff, T. E., & Tucker, C. J. (1985). Multitemporal dimensionality of images of normalized difference vegetation index at continental scales. *IEEE Transactions on Geoscience and Remote Sensing, 23*(6), 888–895.

Townshend, J. R., & Justice, C. O. (1986). Analysis of the dynamics of African vegetation using the normalized difference vegetation index. *International Journal of Remote Sensing, 7*(11), 1435–1445.

Townshend, J., Justice, C., Li, W., Gurney, C., & McManus, J. (1991). Global land cover classification by remote sensing: Present capabilities and future possibilities. *Remote Sensing of Environment, 35*(2–3), 243–255.
Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote sensing of Environment, 8*(2), 127–150.
Van de Voorde, T., Vlaeminck, J., & Canters, F. (2008). Comparing different approaches for mapping urban vegetation cover from Landsat ETM+ data: A case study on Brussels. *Sensors, 8*(6), 3880–3902.
Vashisht, A. K., & Sharma, H. C. (2007). Study on hydrological behaviour of a natural spring. *Current Science, 93*(6), 837–840.
Wang, Q., & Tenhunen, J. D. (2004). Vegetation mapping with multitemporal NDVI in North Eastern China transect (NECT). *International Journal of Applied Earth Observation and Geoinformation, 6*(1), 17–31.
Weng, Q., Lu, D., & Schubring, J. (2004). Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment, 89*, 467–483.
Whyte, A. V. (1986). *Guidelines for planning community participation activities in water supply and sanitation projects*. WHO.
Xie, Y., Sha, Z., & Yu, M. (2008). Remote sensing imagery in vegetation mapping: A review. *Journal of Plant Ecology, 1*(1), 9–23.
Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing, 24*(3), 583–594.

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