Developing water resources management strategies for South Sikkim District, India
B. C. Kusre, P. K. Bora, Deependra Rai, K. Adhikari, C. Niranjit Khuman and J. Tabing

ABSTRACT
This study was an effort to analyse the problems and prospects of water resource management and for suggesting strategies to meet the perceptive demand of 410 L of water per family during the winter period in South Sikkim district of Sikkim state, India. The district is of hilly terrain with an average rainfall of 1,500 mm per year, yet the district faces acute water shortage during the winter period. The hydro-geological and meteorological characteristics of the sub-watersheds were also studied. The district had very poor soil depth (<50 cm), low water holding capacity of soils (27–28%) with mostly sandy-loam texture. The sub-watersheds were found to have more than 70% first-order streams, higher bifurcation ratio (3.31), higher drainage density (3.99 km/km²) and higher stream density (8.65/km²). Sub-watersheds are mostly elongated with average form factors of 0.21. The rainfall pattern, soil type and morphometry of sub-watersheds indicated poor in situ moisture storage and limited possibility of stream water harvesting. To mitigate the scarcity of water in South Sikkim, the only option left for the planners is to promote household roof water harvesting so that water demand can be met during the average consecutive dry period of 30 days.

Key words | management strategy, morphometric analysis, rainwater harvesting, water availability, water management

INTRODUCTION
The availability of fresh water resource is the precursor of sustainable development. All the world civilisations started with it and still lean on it. However, the growth of human and animal populations, particularly in the developing countries, put added pressure on this limited resource. Climate change has contributed another dimension of stress on this resource with uncertainty. Further, a nexus between development and fresh water consumption cannot be undermined. Competition within and among consumers is also bound to increase with time. In spite of the uncertainty, policy level decisions need to be taken for its development and management as implementation of any policy takes its own time and bears significant impacts (Haasnoot et al. 2012). Hence, it is important to understand the potential, limitations and problems in development of resources which will provide the benchmark for preparation of strategies.

Water resource is variable in time and space. The variability makes rational management a very complex and difficult task even in the best of circumstances. Increased frequency of hydrological disasters (i.e. droughts, storm, and other precipitation- and temperature-related extreme events) due to global environmental and climate changes have exacerbated the water shortage problem in recent years (Wang et al. 2012). Integrated water resources management is recognised as a process that promotes coordinated development of water- and land-related resources in order to maximise economic and social welfare in an equitable
manner without compromising the sustainability of vital systems (Agarwal et al. 2000; Mitchell 2005; UN Water 2012). Teodosiu et al. (2005) defined water resources management with particular attention to the Water Framework Directive to adopt an ecosystem approach, establishing principles and economic tools to protect, conserve and restore all water bodies. Until recently, management was often considered as the exclusive task of technical experts working under the auspices of the state. Their activities were based on the assumption that water and natural resources can be protected and controlled, notably by means of infrastructural works. However, the scope of management includes assessment, planning and implementation.

It is a general perception that water resources management activities are more relevant in rain-scarce areas, but their need has been felt even in high rainfall areas. It has been reported that places like Cherrapunji, which receives the highest rainfall in the world, suffers from drought for almost 9 months of the year (Agarwal 2000; Kumar et al. 2005). Such situations also exist in other hilly states of the northeastern (NE) part of India that receive significantly high rains.

Sikkim is one such state of NE India located on the Eastern Himalayan ranges that suffers from shortage of water, particularly during winters when there is very little rain (Figure 1). The water stress situation in the state results in shortage of drinking water, incidences of forest fires, incidences of pest and diseases, drop in productivity, etc., that have a direct bearing on the economy of the state. The increasing population and changing climatic pattern are also attributed to such water stress (Tambe et al. 2011). The state is characterised by highly undulating terrain with elevations ranging from 300 to more than 8,000 m. The population of the state as per the 2011 census is 0.611

Figure 1 | Location map of Sikkim and South District of the state.
million. Around 70% of the population resides in rural environments. The majority of the population thrives on livelihoods linked to natural resources such as agriculture and forest products. These livelihood options are susceptible to the vagaries of climate. Administratively, the state is divided into four districts, namely, East, West, North and South. The present study was undertaken in one of the most stressed areas, the South District of the state with the objective to identify (i) the extent of stress of the water resources, (ii) the constraints related to harvesting/conservation of water resources and (iii) identification of management options for improving the availability of water resources to common households.

DESCRIPTION OF THE STUDY AREA

The South District of Sikkim is a small district with a geographical area of 754 sq km. The population of the district is only 0.146 million (Chandramauli 2011) with 80% residing in rural and isolated locations (Figure 1). The topography of the district is characterised by high elevation (ranging from 300 to 5,000 m), and steep and inaccessible terrain. The northern part of the district comprises high snow-covered mountains and has no habitation. Most of the habitation is concentrated in the central and southern part of the district in the elevation range of 500–2,500 m. People generally live at higher elevations as very narrow deep valleys are not suitable for settlements. Due to this reason, it is very difficult for any household to fetch water from perennial stream sources flowing in the deep and narrow valleys. Steep and undulating terrains also offer limited scope for conventional water conservation techniques. It has been reported that 80% of the households are dependent on the springs as source of water or diversions from nearby small streams that are seasonal in nature. With the changes in climatic patterns and land use, drying of springs has been reported in the state (Tambe et al. 2012).

METHODOLOGY

The present study was conducted by performing the following:

(i) Stakeholders’ perception analyses
(ii) Water availability analyses
(iii) Topographic and morphometric analyses to understand hydrological behaviour
(iv) Pedological and geological analyses of the district for the scope of water harvesting
(v) Strategy formulation based on the hydro-geological findings.

Stakeholders’ perception on water crisis

Before analysing the meteorological and hydro-geological factors affecting water availability and potential for development, stakeholders’ perceptions on water scarcity and requirement were analysed. Participatory rural appraisal (PRA) study was conducted in four randomly selected Gram Panchayat Units (GPU – village level administrative units) taking 11 wards with 120 respondents (Kusre et al. 2016).

Water availability analysis

Rainfall data were collected from three automatic weather stations, namely, Melli, Temi and SIRD Karfactor (Figure 2), installed in the district by the India Meteorological Department (IMD) (as available at MOSDAC (Meteorological and Oceanographic Satellite Data Archival Centre) programme of Government of India).

There are two distinct seasons of rainfall in Sikkim. They are April to September (monsoon season) and October to March (winter non-rainy season). About 90% of total annual rainfall occurs during the monsoon period. The rainfall was analysed for monthly distribution, events of different intensities and number of consecutive dry days. The rainfall intensities were broadly categorised into eight groups for the present study: ≤2 mm, 3–5 mm, 6–8 mm, 9–11 mm, 12–15 mm, 16–20 mm, 21–30 mm and >30 mm. We also categorised the consecutive dry days into eight broad categories: 1–2, 3–5, 6–8, 9–11, 12–15, 16–20, 21–30 and >30.

Soil and geology of the study area

The soil basically acts as a reservoir that can store water. The invisible water contributes immensely to the plant kingdom and supports agriculture to a great extent even without
irrigation. Soil samples were collected from 16 locations (Figure 2) to analyse texture and water holding capacities. Soil moisture characteristic curves were developed for two different locations of the district using a pressure plate pressure membrane apparatus. Soil depth was also measured at each sampling location.

The soil map for the district was prepared from the base map available at the National Bureau of Soil Survey and Land Use Planning, Nagpur (NBSS-LUP). NBSS-LUP is a Government of India recognised organisation that has the mandate to prepare soil maps in India. A soil map at a scale of 1:250,000, prepared by NBSS-LUP was available for the study area. The soil map obtained from NBSS-LUP was scanned and geometrically transformed to the appropriate location on the blank raster. The mapping units of the study area were digitised in Arc-GIS 9.3. A total of 48 mapping units were available for South Sikkim (Figure 3).

The geology of any area controls the infiltration and subsurface movement of water. The geological map was obtained from the Geological Survey of India. The dominant geological formations of the districts were extracted from the map on Arc GIS 9.3 platform.

Terrain and stream network

The terrain map was generated from the Cartosat DEM (digital elevation model) available from National Remote Sensing Centre, Hyderabad (India). Based on the terrain map we delineated the entire districts into sub-watersheds using the Spatial Analyst Extension available in Arc GIS software. The delineation was made using 1,000 ha as threshold value. The extracted DEM was used to estimate different
physical parameters such as area, perimeter, slope length, stream length and different morphometric parameters.

The stream information of South Sikkim District was extracted from the digital data provided by the Department of Science and Technology, Government of Sikkim. The digital data were prepared at 1:50,000 scale using Arc-GIS software (version 9.3). The digital data were geo-referenced and stream networks were digitised using the capabilities of Arc-GIS tools. The digitised streams were ordered on the basis of Strahler’s stream ordering method.

Morphometric analysis

The parameters considered in the study were bifurcation ratio, drainage density, stream frequency, form factor and drainage texture. These parameters indicate the drainage pattern of any area. The methods for estimation of these parameters are shown in Table 1.

The bifurcation ratio ranges from 3 to 5 for well-developed drainage networks (Horton 1945; Strahler 1957). High bifurcation ratio indicates early hydrograph peak with a potential for flash flooding during storm events.

The drainage density generally varies from 0.55 to 2.09 km/km² in humid regions (Langbein 1947). According to Nag (1998), low drainage density generally results in areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. According to Carlston (1963), drainage density is inversely related to permeability of the terrain.

Stream frequency reflects the degree of dissection of the terrain. The higher the stream frequency, the greater is the degree of dissection. It is affected by permeability, infiltration capacity and relief of watersheds.

The value of form factor varies from 0 for a highly elongated shape to unity, i.e. 1 for a perfect circular shape (Horton 1932).

Drainage texture ($R_t$) is influenced by infiltration capacity. There are five different texture classes (Smith 1950): very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8). Hydrologically, very coarse texture watersheds have large basin lag time periods followed by coarse, fine and very fine texture classes (Alt et al. 2015).

RESULTS AND DISCUSSION

Perception of stakeholders

The PRA exercise revealed that there exists water stress in the district and availability reduces from October until May for both agricultural and domestic uses (Figures 4 and 5). The springs, which are the most common source of water, dry up during this period. The habitations in the district are concentrated on the ridges; thereby, the crisis becomes more acute during winter. Water demand is basically for domestic purposes, under five categories: cooking, washing, bathing, cleaning and toilet. About 410 L of water is the average demand for any family of five, which is the value mentioned by the Planning Commission, Government of India (presently known as Niti Ayog).

Water availability analysis

The rainfall pattern indicated that 90% of the rainfall occurs during April to September. The station-wise rainfall pattern in the South District is shown in Table 2.

Table 1 | Morphometric parameters considered in the study

<table>
<thead>
<tr>
<th>Morphometric parameters</th>
<th>Symbol</th>
<th>Formula</th>
<th>Value in the study area</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bifurcation ratio</td>
<td>$R_b$</td>
<td>$R_b = Nu/Nu_{u+1}$ $Nu_{u+1} = \text{number of stream } u_{u+1}$ order</td>
<td>3.31</td>
<td>Schumm (1956)</td>
</tr>
<tr>
<td>Drainage density (km/km²)</td>
<td>$D_d$</td>
<td>$D_d = L/A$ where, $A =$ basin area (km²)</td>
<td>3.99 km/km²</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>Stream frequency (km/km²)</td>
<td>$F_s$</td>
<td>$F_s = Nu/A$</td>
<td>8.65 km²/cm²</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>Form factor</td>
<td>$R_f$</td>
<td>$R_f = A/Lb^2$</td>
<td>0.2067</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>Drainage texture</td>
<td>$R_t$</td>
<td>$R_t = \text{No. of stream/perimeter of the basin}$</td>
<td>5.13</td>
<td>Horton (1945)</td>
</tr>
</tbody>
</table>
Rainfall characterisation

The type of rainfall event has a significant impact on rainwater harvesting potential. The results of the characterisation are shown in Table 3. Generally, rainfall amounts greater than 8 mm have significance in stream water harvesting (Zerizghy et al. 2012). The analysis revealed that most of the rainfall (40–50% for different stations) occurring during the lean season was less than 2 mm. Further, the analysis showed that 65–80% of the rainfall events had a rainfall amount less than 8 mm. This indicates the scope of limited potential of stream harvesting.

Average dry days between two rainfall events

The dry days between two consecutive rainfall events were estimated for the available rainfall records during the lean season. This indicated the average volume of storage of...
water required to meet the demand of fresh water in the event of scarcity. It was observed that average maximum dry days between two rainfall events are 30 days. The highest dry days (59 days) between two rainfall events were recorded in SIRD Karfactor station in South Sikkim District.

The numbers of dry days recorded between two events are shown in Table 4.

### Soil analysis

The soil of the district was found to be mostly sandy loam with a limited depth of 40–50 cm (Table 5). The available water holding capacity was also found to be only 27–28%. The soil moisture measurements indicated rapid fall of soil moisture leading to an increase in suction potential. The soil map, as prepared by NBSS-LUP, reported that around 50% of the soil was excessively drained, having slight to moderate stoniness, coarse loam, associated with severe erosion and was located on slopes in the range of 30–50%.

### Table 3 | Rainfall characterisation for different stations in Sikkim

<table>
<thead>
<tr>
<th>Station</th>
<th>Number of rainfall days with rainfall quantity (mm)</th>
<th>Total days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melli</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Temi</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>SIRD_karfacter</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

### Table 4 | Number of consecutive dry days for each station for peak period

<table>
<thead>
<tr>
<th>Station</th>
<th>Maximum dry days</th>
<th>0–2</th>
<th>3–5</th>
<th>6–8</th>
<th>9–15</th>
<th>16–30</th>
<th>&gt; 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melli</td>
<td>21</td>
<td>38</td>
<td>17</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Temi</td>
<td>12</td>
<td>20</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SIRD_karfacter</td>
<td>59</td>
<td>26</td>
<td>36</td>
<td>12</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 5 | Soil analysis of soil samples collected in South Sikkim District

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Name of the place</th>
<th>Depth of soil (cm)</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Melli Dara</td>
<td>50</td>
<td>27.084</td>
<td>88.418</td>
<td>25.4</td>
<td>31.6</td>
<td>43</td>
<td>Silty clay loam</td>
</tr>
<tr>
<td>2</td>
<td>Lower Payong</td>
<td>30</td>
<td>27.101</td>
<td>88.415</td>
<td>24.68</td>
<td>35.75</td>
<td>39.57</td>
<td>Silty clay loam</td>
</tr>
<tr>
<td>3</td>
<td>Bermiok Pabong</td>
<td>30</td>
<td>27.229</td>
<td>88.447</td>
<td>13.1</td>
<td>22.59</td>
<td>64.31</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>4</td>
<td>Ravanngla</td>
<td>30</td>
<td>27.291</td>
<td>88.354</td>
<td>13.992</td>
<td>17.508</td>
<td>68.5</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>5</td>
<td>Legship (NHPC)</td>
<td>30</td>
<td>27.283</td>
<td>88.283</td>
<td>13.1</td>
<td>15.8</td>
<td>71.2</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>6</td>
<td>Bermiok Farm</td>
<td>40</td>
<td>27.273</td>
<td>88.593</td>
<td>14.42</td>
<td>5.908</td>
<td>74.57</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>7</td>
<td>Bermiok Orange Field</td>
<td>10</td>
<td>27.290</td>
<td>88.593</td>
<td>9.668</td>
<td>6.418</td>
<td>76.24</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>8</td>
<td>Namthang Middle Phong</td>
<td>10</td>
<td>27.181</td>
<td>88.454</td>
<td>14.42</td>
<td>6.09</td>
<td>77.9</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>9</td>
<td>KVK Namthang</td>
<td>10</td>
<td>27.167</td>
<td>88.480</td>
<td>18.092</td>
<td>5.66</td>
<td>71.24</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>10</td>
<td>Gaddi Khola Sample 1</td>
<td>50</td>
<td>27.224</td>
<td>88.397</td>
<td>19.44</td>
<td>21</td>
<td>59.56</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>11</td>
<td>Gaddi Khola Sample 2</td>
<td>10</td>
<td>27.224</td>
<td>88.398</td>
<td>20.16</td>
<td>5</td>
<td>74.84</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>12</td>
<td>Kamrang Agri Area Sample 1</td>
<td>50</td>
<td>27.177</td>
<td>88.347</td>
<td>26.16</td>
<td>20.28</td>
<td>53.56</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>13</td>
<td>Kamrang Agri Area Sample 2</td>
<td>50</td>
<td>27.177</td>
<td>88.347</td>
<td>17.88</td>
<td>16</td>
<td>66.12</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>14</td>
<td>Mamley Agri Area Sample 1</td>
<td>35</td>
<td>27.357</td>
<td>88.559</td>
<td>15.44</td>
<td>21.28</td>
<td>65.28</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>15</td>
<td>Mamley Agri Area Sample 2</td>
<td>25</td>
<td>27.182</td>
<td>88.362</td>
<td>13.44</td>
<td>9.28</td>
<td>77.28</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>16</td>
<td>Mamley Agri Area Sample 3</td>
<td>45</td>
<td>27.084</td>
<td>88.418</td>
<td>14.44</td>
<td>16</td>
<td>69.56</td>
<td>Sandy loam</td>
</tr>
</tbody>
</table>
In such soils, where water holding capacity is significantly lower, *in situ* water conservation within the soil profile is not a viable option. Further, for profitable crops, if one wants to provide irrigation, such types of soils require light and frequent irrigation.

**Digital elevation model of South Sikkim**

The DEM indicated that the elevation of South Sikkim ranges from 500 to 5,000 m from MSL (Figure 6). The analysis of DEM indicated that more than 78% of the area was below the elevation of 2,500 m. The habitation in the district was mainly concentrated in the elevation range of 500–2,500 m. The DEM was also used to study the slope of the district. The map indicated that the district was dominated by steep terrain with 50% and 36% of the area falling under 15–30% and 30–45% slope categories, respectively (Figure 7). The steep slope of the district indicated the quick drainage with poor infiltration opportunity time.

**Stream network of the district**

The stream network was also analysed for South District (Figure 8). The results indicated the dominance of first- and second-order streams (>70%). The total length of the streams in the district was found to be 2,450 km, of which, 1,722 km (70%) of the streams are first-order. The details of the stream network are shown in Table 6.

Typical characteristics of the first-order streams are shallow depth and small upstream catchment. These streams have less water carrying capacity coupled with quick and excessive drainage, with impermeable structure in the watershed and steep terrain.

**Morphometric analysis**

The values of morphometric parameters are shown in Table 3. The parameters indicated that the sub-watersheds in the district had high runoff potential. In the present
study, the average value of bifurcation ratio ($R_b$) was estimated at 3.31. This indicated that overland flow was the dominating process in the sub-watersheds. The drainage density ($D_d$) of sub-watersheds of the district was 3.99, indicating high runoff generation capabilities. The drainage densities ranging from less than 1 to nearly 10 were associated with discharges ranging from 0.02 to 2.19 lps per hectare (Gregory & Walling 1968). The drainage density $D_d$ was directly proportional to discharge $Q$. In these watersheds the runoff was higher due to impermeable sub-surface leading to reduced infiltration. The stream frequency ($F_s$) of the whole basin was high (8.65 km$^{-2}$). The higher value indicated impermeable sub-surface materials and high relief conditions and low infiltration capacity (Ozdemir & Bird 2009). Such watersheds contribute to higher runoff. The parameter, form factor ($F_f$), indicated the flow intensity pattern and runoff disposal response to any rainfall for any watershed. The $F_f$ of South Sikkim was high (0.2067), indicating slow infiltration rate and high runoff. The drainage texture ($R_t$) in the study area was 5.13 which fell under the fine category. Such areas exhibit quick drainage characteristics.

**STRATEGY FOR WATER RESOURCE MANAGEMENT**

The soil, terrain, rainfall characteristics indicate the limited scope of conventional water harvesting. It is therefore essential to devise an appropriate strategy for water resources management. The perception of the stakeholders and the basic characteristics of the district need to dovetail. An effort to formulate a prospective strategy for water resources management is discussed below.

**Stakeholders’ perception for water resources management**

District administration is often under pressure to supply water during the winters. It is often nearly impossible to have pipe networks among the ridges due to both financial and technical limitations; hence, it is on the lookout for alternative means to create water resources at different locations in the state. Technically, water harvesting is the only option to mitigate the demand of water. The residents’ perception of scarcity is limited to winters; hence, augmentation of supply should be the strategy instead of entirely depending on the harvested water. Some important points were revealed during PRA: (a) respondents were aware of acute shortage and the limitations; (b) they expressed the desire to take up water storage activities; and (c) they were willing to contribute and support any administrative programme.
It was obvious from the hydrogeological study and the morphometry of the sub-watersheds that due to shallow and porous sandy loam soils dug-out water harvesting was not feasible. The topography (Figure 6) also does not permit on-stream water harvesting structures of larger capacity. Hence, the only option left is rainwater harvesting on a household basis, either through above-ground lined tank or roof water harvesting through portable storage tanks.

**Prospective action suggested**

Based on stakeholders’ perceptions, hydrogeology and soil characteristics of the district, the following prospective actions may be suggested for augmenting water supply to the residents.

**Roof top rainwater harvesting**

The technique of roof top water harvesting has been found to be successful in hilly areas. However, it is impossible to harvest the entire water coming from the catchment of a single household roof due to high rainfall in South Sikkim. The capacity of storage structures will depend on individual household demands and a suitable location for the storage tank or structures. Invariably, all the structures will be accompanied by a spill-over arrangement without causing any soil erosion in the downstream due to concentrated outflow from the tanks. The roof tops of South Sikkim are mostly level concrete and hence drain pipes are arranged in a systematic manner. The only work left is to provide outflow direction for the storage structures. The edges of the gable, even corrugated galvanised iron (CGI) sheet roofs, can also be provided with a CGI gutter and collect the outflow at a single point. The residents may arrange a series of tanks of 1,000–2,000 L capacity on the hill slope so that the downstream tanks can collect the spill-over water from the upstream tank and so on, thereby capacity of storage can be increased considerably. The administration may also consider not approving any government or private new construction without the provision of roof top water harvesting. Alternatively, the administration may also consider providing incentives for roof top water harvesting arrangement in new constructions.

**Micro irrigation system**

With <50 cm soil depth, the sub-watersheds can sustain only shallow rooted crops. Poor water holding capacity also causes rapid water depletion in the root zones. Under such soil physical conditions, light and frequent irrigation is required for any crop. Agriculture is the mainstay of the residents of the districts. Vegetable growing is a major agricultural activity along with poultry and dairy. Any prospective plant for water resource development cannot ignore agriculture as it is an important consumer. Micro irrigation, especially drip irrigation, should be promoted among the vegetable growers so that demand for water in the agriculture sector is reduced. Gravity-fed drip irrigation connected to roof top harvesting tanks or rainwater harvesting tanks located upstream to the cropped area is the best option for South Sikkim.

**Diversification of livelihood activities**

It was observed that some farmers have diversified from agriculture to livestock farming (namely, dairy and poultry). Thus, it is suggested that emphasis should be placed on promotion of non-farm livelihood avenues. Such observations were also reported by other researchers (Barua et al. 2015). They stressed the need for improvement of market access in the vicinity for diversification of agricultural patterns that can supplement agricultural income, which would enhance communities’ resilience to any unforeseen climate extremes. This can be achieved by the skill development programme initiated by the state government.

**Springs’ rejuvenation programme**

Springs are the lifeline of the people of Sikkim. Streams are gradually drying up due mostly to over-consumption and catchment denudation. Sikkim has successfully implemented forest conservation policies. It is time the government took up comprehensive spring rejuvenation programmes so that the flow period in hilly streams could be increased. An increased flow period will reduce water scarcity during winters.
CONCLUSIONS

The South District of Sikkim has hilly terrain with people living on the ridges of hills. The inhabitants are heavily dependent on springs and streams for fresh water. Water scarcity in winters is mostly due to dried natural sources and scanty rainfall. The present study tried to find out the potential of augmenting water supply in the district. The hydro-geological analyses as well as the morphometry of the sub-watershed in the district indicated poor soil depth (<50 cm) and sandy loam soils with low water holding capacity. The higher drainage density (3.99 km/km²) availability of nearly 70% of first-order streams also indicated very poor infiltration opportunity or watershed retention of rainwater. In situ water conservation for crops and water harvesting structures in the valleys have very low potential. It is therefore concluded that the only feasible option left was roof top water harvesting and small-scale household rainwater harvesting. The prospective action for augmenting water supply may include the following:

(a) Mandatory roof top water harvesting plan for new construction.
(b) Existing houses may be provided with collection networks so that water can be harvested from the roof catchment in above-ground tanks at a suitable location.
(c) Series of tanks can be planned on hill slopes to catch spill-over rainwater from upstream tanks to downstream tanks.
(d) Shallow rooted crops should be chosen for light and frequent irrigation through drip or micro irrigation systems.
(e) Non-cropped and low water demand livelihood activities may be promoted.
(f) The government should undertake a comprehensive spring rejuvenation programme for sustainability of the present resources.

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