Technical Report

WATER AT A GLANCE

UTTARAKHAND

An assessment of Water Scarcity

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The drinking water supplies in the mountains of Indian Himalaya are mostly dependent on natural springs, streams and rivulets. Over 50 percent of the local people of in the region depend on these natural water resources to meet their water requirements. However, during the last few decades, water discharges from these natural water resources are reported to be increasingly diminishing due to ever increasing anthropogenic and climatic pressure. As a result, fresh water scarcity throughout the Indian Himalaya has emerged as a major socio-environmental problem. Therefore, realizing the need to ensure long-term sustainability of fresh water supply to the Himalayan inhabitants, the GB Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Almora, under the over all guidance of Ministry of Environment, Forest & Climate Change (MoEFCC), GOI, has initiated Gram Jal Abhyaranya Programme that covers one identified districts in each of the 12 Indian Himalayan States. The programme also considers at least one drying spring in each of over 50,000 villages of the Indian Himalaya for rejuvenation. However, to successfully implement the Gram Jal Abhyaranya Programme in the region, a precedentary detail of fresh water scarcity assessment is necessary at administrative block level for each Indian Himalayan state. This report is, therefore, prepared to highlight the current situation of natural water sources used for fresh water supply in the state of Uttarakhand along with administrative block-wise geospatial assessment of water scarcity. The report is anticipated to be beneficial for proper field implementation of Jal Abhyaranya Programme. Moreover, the policy makers are also expected to be benefitted for developing sustainable fresh water management strategies. It is further proposed to continue with publication of such reports for remaining states of Indian Himalaya.

Dr. R.S. Rawal
(Director)
Preface

In spite of significant improvement with respect to distribution of fresh potable water to the residents of the India Himalayan region, a significant proportion of the Himalayan dwellers are still deprived of uninterrupted supply of fresh potable water through tapped schemes. Since, water supply in the IHR largely depends on climate sensitive natural water resources, such as rivulet, springs and streams, etc., a sustainable water management in the extremely mountainous terrain of Himalaya requires physical and social accounting of water based on availability and demand. As the physical water budgeting at a regional scale is extremely non-trivial, source-wise assessment of water supply schemes over the IHR, as an initiation to physical water accounting, is expected to highlight natural water resources that are majorly harvested and need immediate attention. Thus, this report is aimed to highlight the current situation of natural water sources used for tapped water supply for the state of Uttarakhand, and prioritized list of natural water resources harvested for maximum benefit to the society as well as under maximum usage threats. Moreover, the report is expected to shed light on fresh water vulnerability through an integrated index based approach wherein hydrological, environmental and demographic factors are integrated. Therefore, the report is anticipated to be extremely beneficial for policy makers for developing targeted intervention strategies for sustainable usages of water resources in the Indian Himalayas.
The Indian Himalaya contain over half the permanent snow and ice fields outside the Polar Regions. Consequently, the Himalayas are having more than 33,000 square km of glaciated basins that store approximately 12,000 cu. Km of fresh water[1] sustaining around 1.5 billion people of India, Nepal, Pakistan, Bhutan and Myanmar[2]. Around 16% of the total area of Hindu-Kush Himalaya is having fresh water wetlands, and more than 9000 glaciers could be found in the Indian Himalayan region (IHR)[3] along with numerous springs, streams and seepages serving as primary sources of fresh water. Although historically the water resources of mountains, such as springs, streams, rivulets, etc. were managed by the mountain community for sustainable usages, since the early 1970s these natural water resources of the Indian Himalayan regions are being tapped by Accelerated Rural Water Supply Programme (ARWSP) of state and regional governments so that uninterrupted fresh and potable water supply could be made. Currently, the National Rural Drinking Water Programme (NRDWP) is aimed at providing fresh potable water to natives of India including Himalayan dwellers. However, year-round uninterrupted availability of fresh potable water though piped government schemes to every household of the Indian Himalayan region remained a significant challenge, for example, as of 2013 a total of 26993 of 39142 habitations of Uttarakhand is having water supply coverage[4]. Water supply in the IHR through government schemes has experienced setbacks due to ineffective management and unaddressed logistical issues[5]. Moreover, with ever increasing water consumption trend, as global water demand is increasing with an annual rate of 1% during the last few decades[6], there is considerable pressure on individual water supply scheme. Success and sustainability of a water supply schemes over the IHR is also dependent on the physical behavior of the natural water resources that are being tapped. Under the current context of climate change, wherein the Himalayas are having higher than the average global warming rate with enhanced negative impact of climate change on ecosystems and water resources[7,8,9], behaviors of these natural water resources are being increasingly becoming unpredictable resulting significant impact on water availability. Subsequently, NITI Aayog, GoI has also indicated that special efforts should be made to protect natural springs and streams of the IHR on an urgency basis for long-term sustainable availability of fresh water[10]. However, a sustainable potable water management in the extreme mountainous terrain of Indian Himalaya requires physical and social accounting of water based on availability and demand. This would further be anticipated to address the Sustainable Development Goal number 6 of the United Nation framed in 2015, related to availability and sustainable management of water and sanitation for all. Subsequently, the first step for physical budgeting of water cycle would be to assess distribution of natural water resources that are being used as potable water sources within a state or a region. Numerical quantification of such water sources used for tapped water supply are also anticipated to highlight pressure-scenarios that could be used for identifying water scarce area or region where immediate governmental intervention is solicited. Since, complete water budgeting based on demand and availability of a state or a union territory is extremely non-trivial, source-wise assessment of water supply schemes over the IHR is expected to highlight natural water resources that need immediate attention. Moreover, due to unavailability of such elaborate information or assessment of source wise distribution of water supply schemes over the Indian Himalayas, this report is aimed to highlight the current situation of natural water sources used for tapped water supply for the state of Uttarakhand. Therefore, this report would be providing a prioritized list of natural water resources harvested for maximum benefit to the society as well as under maximum usage threats. Moreover, the report is expected to shed light on freshwater vulnerability through an integrated index based approach wherein hydrological, environmental and demographic factors are integrated. Therefore, the current report is organized such that a brief description of the Uttarakhanda state would be provided with an emphasis to water resources. The methodology section would briefly describe the data and analysis method for assessing natural source wise distribution of water supply schemes in every block of the Uttarakhanda, along with a brief description of integrated index based approach for water scarcity. Finally, status of water resource availability and vulnerability would be described in the results section, and a summary of the assessment with few recommendations would be made at the end.

5Negi and Joshi (2002): Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. Mount Ris Dev. 22:29-31
9Negi and Joshi (2002): Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. Mount Ris Dev. 22:29-31
The state of Uttarakhand was established as 27th state of India in November 2000, and had given special category status by Union of India due to its strategic and geographic location. The topography of Uttarakhand is characterized by hilly and rugged terrain, deep valleys, high peaks, sharp stream and rivulets, rapid soil erosion, frequent landslides and widely scattered population. The state shares its international boundary with China in north-east and Nepal at its south-east while within the country its neighbouring states are Himachal Pradesh and Uttar Pradesh. Geographically it extends from 28°43’ to 31°27’ N (latitude) and 77°34’ to 81°02’ E (longitude) with the total area of 53,483 km² including 86.07% hilly area and 13.93% plain area. The Uttarakhand state consists of 13 districts which are grouped administratively into two divisions — Kumaun and Garhwal. There are 6 districts in Kumaun division and 7 districts in Garhwal division. Under 13 districts there are 110 tehsils and 18 sub tehsils and 95 developmental blocks (Table 1). The state geographically consists of three zones i.e upper hills, middle hills and foothills. Upper hills include Uttarkashi, Chamoli, Rudraprayag, Pithoragarh and Bageshwar, middle hills include Tehri-Garhwal, Pauri-Garhwal, Almora, and Champawat, the hill regions of Nainital and Champawat tehsil of Dehradun and foothills include Nainital. Among all the districts of Uttarakhand, Chamoli is having highest geographical area (Figure – 1a). District-wise population of Uttarakhand is provided in Figure – 1b. According to census 2011, the state has total population of 10,086,292. Maximum population was noted in Haridwar and lowest population was noted in Rudraprayag.

### Table 1: Developmental blocks of Uttarakhand

<table>
<thead>
<tr>
<th>Name of the Districts</th>
<th>Name of the Blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bageshwar</td>
<td>(i) Bageshwar, (ii) Garur, (iii) Kapkote</td>
</tr>
<tr>
<td>Champawat</td>
<td>(i) Barotkot, (ii) Champawat, (iii) Lohaghat, (iv) Pati</td>
</tr>
<tr>
<td>Rudraprayag</td>
<td>(i) Augustmuni, (ii) Jakholi, (iii) Udhamth</td>
</tr>
</tbody>
</table>

### Table 2: Major water resources of Uttarakhand.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>District</th>
<th>Drainage</th>
<th>Major rivers/ tributaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Almora</td>
<td>River</td>
<td>Kosi, Ramganga, Suyal, Gagan, Phikka</td>
</tr>
<tr>
<td>2</td>
<td>Bageshwar</td>
<td>River</td>
<td>Saryu, Gomti and Pindar</td>
</tr>
<tr>
<td>3</td>
<td>Chamoli</td>
<td>River</td>
<td>Alikundia, Ramganga, Dhuliganga, Nandakini, Pindar</td>
</tr>
<tr>
<td>4</td>
<td>Champawat</td>
<td>River</td>
<td>Surya, Kali, Sada</td>
</tr>
<tr>
<td>5</td>
<td>Dehradun</td>
<td>River</td>
<td>Aanu, Sor, Toms, Riosina</td>
</tr>
<tr>
<td>6</td>
<td>Haridwar</td>
<td>River</td>
<td>Ganga, Solai</td>
</tr>
<tr>
<td>7</td>
<td>Nainital</td>
<td>River</td>
<td>Kosi, Gola, Haridwar, Dhikko, Bheru and Bhakra</td>
</tr>
<tr>
<td>8</td>
<td>Pauri Garhwal</td>
<td>River</td>
<td>Ganga, Alikundia, Nayar</td>
</tr>
<tr>
<td>9</td>
<td>Pithoragar</td>
<td>River</td>
<td>Gogringa , Kali river, Surya, Ramganga, Yangti, Dhauli and Kuti</td>
</tr>
<tr>
<td>10</td>
<td>Rudraprayag</td>
<td>River</td>
<td>Mandakini, Alikundia</td>
</tr>
<tr>
<td>11</td>
<td>Tehri Garhwal</td>
<td>River</td>
<td>Bhagirathi, Bhilangana, Alikundia, Ganga</td>
</tr>
<tr>
<td>12</td>
<td>Udham Singh Nagar</td>
<td>River</td>
<td>Sarada, Gola, Phikka</td>
</tr>
<tr>
<td>13</td>
<td>Uttarkashi</td>
<td>River</td>
<td>Bhagirathi, Yamuna, Tom</td>
</tr>
</tbody>
</table>

The state is fed with different glacier fed and perennial rivers and their tributaries along with other ground water sources (Table 2). Due to the availability of water through glacier fed rivers in many districts of the state, various hydropower projects are running on the rivers Yamuna, Bhagirathi, Bhilangana, Alaknanda, Mandakini, Saryu, Gauri, Kosi and Kali, through which approximately 25,450 MW are being produced (https://knowindia.gov.in/states-uts/uttarakhand.php). State receives an average rainfall of 1631 mm. and temperature generally ranges from -3.4°C to 37°C.
3.1 Data and analysis for assessing source wise distribution of water supply schemes

In order to assess source wise distribution of water supply schemes in every block of the Uttarakhand state, water supply data was downloaded from the Ministry of Jalshakti, GoI, IMHS web server updated till 31st July, 2019. Total number of water schemes harvesting natural resources was compiled for each block. In order to have a simplified visual comparison, pie charts are produced on percent distribution of fresh water resources harvested for water supply. The generic color code for the following sources is kept similar so that easy visual comparison could be made: (i) Deep tube well, (ii) Khdins / Nadins/ Tankas/ Ponds / Wells/ Ooranis, (iii) Infiltration well, (iv) River, (v) Rivulet / Naula / Gadhera, and (vi) Spring. The terminology ‘Naula’ cannot be considered synonymous to ‘Spring’, rather it represents a form of surface flowing water. Consequently, in spite of two different categories representing different form of ground water; these two categories could be conjectured to be generic forms of ground water out-flow in the hilly terrains of Himalaya. The standard color codes used for these individual classes in the pie chart are provided in Figure 2. This is also to be noted that instead of using the larger nomenclature for the pie chart, the categories (i) ‘Ponds / Wells’ / ‘Ooranis’, the pie charts include the smaller nomenclature ‘Khadins / Nadins/ Tankas/ Ponds / Wells/ Ooranis’.

3.2 Data and analysis for integrated index based approach for water vulnerability

The integrated index based approach for assessing fresh water vulnerability within Uttarakhand was adopted using the generic water sustainability framework of Chavez and Alipaz (2007)[1]. The index used for estimating vulnerability was ‘Water Sustainability Index’ (WSI). The range of WSI can vary between 0,1, where a value of 0 indicates highest water scarcity and 1 indicates lowest water scarcity. The five components of WSI were Hydrology (H), Environment (E), Life (L), Rainfall (R) and Vertical Proximity (Pr) as indicated in Box-1. The WSI was estimated at a block level. Digital and geo-referenced Uttarakhand administrative block boundary was prepared at GPBNHESD, Almora. The digital imagery was co-registered using exiting ground control point (GCPs) to remove the geo-referencing errors. The boundary was projected using <<WGS 1984 UTM ZONE 44N>>. All the ninety five blocks of Uttarakhand were mapped and depicted in the block boundary. The block level Hydrology index map was prepared, first, by using high resolution Digital Elevation Model (DEM) data of Alos Palsar at 12.5 m, mosaiced and clipped along the state boundary. Subsequently, ‘Fill’, ‘Flow direction’, ‘Flow accumulation’, ‘Four points’, etc. maps were prepared to derive the ‘Drainage and watershed boundary’ of the Uttarakhand state. Distribution of the block boundary was geospatially analyzed to produce the average elevation map at block level for the state. Next, four further major components of hydrology indices were geospatially mapped: (i) Demography and water demand, (ii) Cattle distribution and water demand, (iii) Water availability from major rivers, and (iv) Block-wise total Water availability and Demand. The Demography data was integrated geospatially with the block boundary of the state to prepare the water demand map. The census 2011 demography data from the www.censusindia.gov.in website of Office of the Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India was downloaded and compiled at block level to categorize the rural, urban and total population of the Uttarakhand state. The standard per capita water demand in litres per day (Litre Per Capita Demand (lpcd)) was taken to be 40 lpcd for rural population and 135 lpcd for urban population (as per the standards laid down by the World Health Organization or the Bureau of Indian Standards, 1993). Finally, block-wise Demography and water demand was prepared. The cattle census data was integrated geospatially with the block boundary of the state to prepare the water demand map (Table 3). The cattle distribution was then linearly interpolated to each block as a function of demography. A report on Livestock Water Requirement by NDSU Extension Service, July 2015, suggests the water demand of different livestock. The reported figures were utilized to derive the water demand by the different categories of cattle at block level as 20 litres for cow, 30 litres for buffalo, 3 litres for goat and sheep and 7 litres for pig. The total daily water demand by human population and cattle was compiled at the block level as

\[
\text{Water discharge (l/day) = } Q = \frac{90400 \times 1000}{t}
\]

where, Q is the annual average discharge of the river in cubic metre per second. The total daily water availability at block level was computed, first by estimating proportionate block area with respect to total watershed area of a particular river. Finally the daily water availability at block level was estimated by considering 2% of total daily water availability at block level. This is the effective daily water availability at block level. The 2% usages of total daily water availability at block was considered for household use to ensure the sufficient water flow at downstream and also for other water demand such as ground infiltration, irrigation, etc.

To prepare the geospatial Block-wise total Water Availability and Demand, a ratio of total water availability and total water demand at block level was calculated. This ratio was finally used to produce Hydrological Index. The criterion for developing Hydrological Index was the per capita water availability within a block spatial scale. The hypothesis for H index was ‘higher the water availability, higher is the index’. A normalized H index was categorized in to four classes: H = 0.25 (for availability and demand ratio less than 2.0) indicating poor index; H = 0.50 (for availability and demand ratio within 2.0-6.0) moderate index; H = 0.75 (for availability and demand ratio between 6.0 - 10.0) good index.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>District</th>
<th>Cow</th>
<th>Buffalo</th>
<th>Sheep</th>
<th>Goat</th>
<th>Pig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Almora</td>
<td>83548</td>
<td>410988</td>
<td>158072</td>
<td>803911</td>
<td>4716</td>
</tr>
<tr>
<td>2.</td>
<td>Baghpat 628846</td>
<td>149466</td>
<td>264970</td>
<td>485699</td>
<td>351</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Chamoli 604572</td>
<td>165004</td>
<td>3910900</td>
<td>311748</td>
<td>1328</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Champawat 738166</td>
<td>95570</td>
<td>0</td>
<td>210346</td>
<td>1145</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Dehradun 345527</td>
<td>127639</td>
<td>284602</td>
<td>329484</td>
<td>10349</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Garhwal 1227034</td>
<td>156416</td>
<td>1039922</td>
<td>725793</td>
<td>2962</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Hardwar 602411</td>
<td>964631</td>
<td>231294</td>
<td>99320</td>
<td>38095</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Nainital 556800</td>
<td>285703</td>
<td>11885</td>
<td>222603</td>
<td>2921</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Pithoragarh 746414</td>
<td>181153</td>
<td>174207</td>
<td>743103</td>
<td>827</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Rudraprayag 408099</td>
<td>341042</td>
<td>48670</td>
<td>160528</td>
<td>327</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Tehri Garhwal 444232</td>
<td>404670</td>
<td>1921615</td>
<td>557834</td>
<td>2826</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Udham Singh Nagar 267617</td>
<td>318005</td>
<td>33592</td>
<td>82860</td>
<td>3359</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Uttarkashi 497102</td>
<td>138825</td>
<td>4216247</td>
<td>542266</td>
<td>909</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: District-wise cattle census data of Uttarakhand, 2012. (Source: Statistics and Census – Animal Husbandry, Govt. of Uttarakhand).

Table 4: Major rivers and mean annual discharges considered for indexing.

<table>
<thead>
<tr>
<th>River Name</th>
<th>Annual Average Discharge (m³/Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kosi River</td>
<td>8.900</td>
</tr>
<tr>
<td>Kulli River</td>
<td>420.700</td>
</tr>
<tr>
<td>Ramganga River</td>
<td>20.101</td>
</tr>
<tr>
<td>Bagmati River</td>
<td>656.000</td>
</tr>
<tr>
<td>Gagas River</td>
<td>15.186</td>
</tr>
<tr>
<td>Satya River</td>
<td>195.500</td>
</tr>
<tr>
<td>Nayyar</td>
<td>32.870</td>
</tr>
<tr>
<td>Ramganga</td>
<td>4.920</td>
</tr>
<tr>
<td>Pinder River</td>
<td>94.290</td>
</tr>
<tr>
<td>Alaknanda River</td>
<td>287.000</td>
</tr>
<tr>
<td>Dhuliaganga River</td>
<td>72.600</td>
</tr>
<tr>
<td>Mandakhan River</td>
<td>105.000</td>
</tr>
<tr>
<td>Bhagirathi</td>
<td>246.440</td>
</tr>
<tr>
<td>Gurganga River</td>
<td>169.000</td>
</tr>
<tr>
<td>Yamuna River</td>
<td>220.000</td>
</tr>
<tr>
<td>Tosi River</td>
<td>5.740</td>
</tr>
</tbody>
</table>

Blue (B2), Green (B3), Red (B4) and Infrared (B5) were integrated to form the composite layers. The satellite imagery was classified for the extraction of vegetation using the object based classification method. Normalized Difference Water Index (NDWI) was utilized to extract the vegetation cover in the state using the threshold value (greater than 0.23). The accuracy assessment of the classification was performed using the existing ground GPS point and Google Earth Engine - High Resolution Imagery. The accuracy of the classification was found to be greater than 85%. Based on the vegetation cover derived from the 30 m Landsat satellite imagery, the Environmental Index at block level was calculated for four classes: E = 0.25 (for less than 25% vegetation cover in the block) moderate index; E = 0.50 (for 25-50% vegetation cover in the block) indicating poor index; E = 0.75 (250-400) good index and E = 1.0 (more than 400) excellent index.

The criterion for developing Vertical Proximity (Pri) index was the mean elevation of individual block. The mean elevation of each block was computed using the available DEM data over the GIS platform to calculate the vertical proximity. This index is useful because the blocks lying at lower elevations were mostly drained by higher order streams and also due to availability of the groundwater extracted through wells. The Pri index is calculated as Pri = 0.25 (for elevation less than 1000 m) indicating poor index; Pri = 0.50 (for elevation within 1000-1500 m) moderate index; Pri = 0.75 (for elevation within 1500-2000 m) good index and Pri = 1.0 (for elevation more than 2000 m) excellent index.

The hypothesis for L index was ‘Higher the population distribution, lower is the index’. Population density at the block scale was estimated using the Census – 2011 data of Gov. Total population was summation of urban and rural population. The population density was calculated for each block and geospatially integrated with the block boundary. The Life index has been calculated in four classes: L = 0.25 (less than 100) indicating poor index; L = 0.50 (100 - 250) moderate index; L = 0.75 (250 - 400) good index and L = 1.0 (more than 400) excellent index.

The criterion for developing H index was ‘Higher the vegetation cover, higher is the index’. The hypothesis for H index was ‘Higher the population distribution, lower is the index’. Population density at the block scale was estimated using the Census – 2011 data of GoI. Total population was summation of urban and rural population. The population density was calculated for each block and geospatially integrated with the block boundary. The Life index has been calculated in four classes: L = 0.25 (less than 100) indicating poor index; L = 0.50 (100 - 250) moderate index; L = 0.75 (250 - 400) good index and L = 1.0 (more than 400) excellent index.

The hypothesis for R index was the mean value of annual rainfall, R index was calculated as $R = 0.25 \text{ for rainfall less than } 1032 \text{ mm} \text{ indicating poor index; } R = 0.50 \text{ for rainfall within } 1032 - 1282 \text{ mm} \text{ moderate index; } R = 0.75 \text{ for rainfall within } 1282 - 1532 \text{ mm} \text{ good index and } R = 1.0 \text{ (for rainfall more than } 1532 \text{ mm) excellent index.}$

The criterion for developing Water Scarcity Index was computed as:

$$WSI = ((0.4 * Pri) + (0.3 * Hi) + 0.1 * (Ei + Li + Ri))$$

Finally, Water Scarcity Index was computed as:

$$\text{Water Scarcity Index} = 1 - WSI$$

Therefore, a value of Water Scarcity Index 0(1) will be representing lowest (highest) scarcity.

The results section is broadly categorized in to two parts. The first part highlights block and district-wise distribution of natural water resources that are being harvested for fresh water supply. The second part highlights blocks and districts that are highly vulnerable as per the integrated index based estimation of water vulnerability.

4.1 Distribution of water sources harvested for water supply

As indicated in the Table 4, there are 13 districts in Uttarakhand of which Pauri-Garhwal is having a maximum total of 15 numbers of Blocks. Brief descriptions of block-wise distributions of water sources in each district used for water supply schemes are provided below.

4.1.1 Almora

- The common generic water sources used for water supply schemes over the districts are:
  - Deep Tube-well,
  - Khasdi / Nadis / Tankas / Ponds / Wells / Oceanis
  - Infiltration well,
  - River,
  - Rivulet / Naula / Gadhera,
  - Spring,
  - Treated Surface Water,
  - Streams

The criterion for developing Vertical Proximity (Pri) index was the mean elevation of individual block. The mean elevation of each block was computed using the available DEM data over the GIS platform to calculate the vertical proximity. This index is useful because the blocks lying at lower elevations were mostly drained by higher order streams and also due to availability of the groundwater extracted through wells. The Pri index is calculated as Pri = 0.25 (for elevation less than 1000 m) indicating poor index; Pri = 0.50 (for elevation within 1000-1500 m) moderate index; Pri = 0.75 (for elevation within 1500-2000 m) good index and Pri = 1.0 (for elevation more than 2000 m) excellent index.

The criterion for developing Life Index (Li) was determining the population distribution within a block spatial scale. The hypothesis for Li index was ‘Higher the population distribution, lower is the index’. Population density at the block scale was estimated using the Census – 2011 data of GoI. Total population was summation of urban and rural population. The population density was calculated for each block and geospatially integrated with the block boundary. The Life index has been calculated in four classes: L = 0.25 (less than 100) indicating poor index; L = 0.50 (100 - 250) moderate index; L = 0.75 (250 - 400) good index and L = 1.0 (more than 400) excellent index.

The criterion for developing Water Scarcity Index was computed as:

$$WSI = ((0.4 * Pri) + (0.3 * Hi) + 0.1 * (Ei + Li + Ri))$$

Finally, Water Scarcity Index was computed as:

$$\text{Water Scarcity Index} = 1 - WSI$$

Therefore, a value of Water Scarcity Index 0(1) will be representing lowest (highest) scarcity.

The results section is broadly categorized in to two parts. The first part highlights block and district-wise distribution of natural water resources that are being harvested for fresh water supply. The second part highlights blocks and districts that are highly vulnerable as per the integrated index based estimation of water vulnerability.

4.1.2 Bageshwar

- The common generic water sources used for water supply schemes over the districts are:
  - Deep Tube-well,
  - Khasdi / Nadis / Tankas / Ponds / Wells / Oceanis
  - River,
  - Rivulet / Naula / Gadhera,
  - Spring,
  - Treated Surface Water,
  - Streams

- The average dependency of water supply schemes over the districts is found to be dependent on Rivulet / Naula / Gadhera (30.3%) followed by Khadins / Nadis / Tankas / Ponds / Wells / Oceanis (25.6%) and Treated surface water (24.2%) are noted to be highly tapped for water schemes in Bageshwar.

- The results section is broadly categorized in to two parts. The first part highlights block and district-wise distribution of natural water resources that are being harvested for fresh water supply. The second part highlights blocks and districts that are highly vulnerable as per the integrated index based estimation of water vulnerability.

4.1.3 Chamoli

- The common generic water sources used for water supply schemes over the districts are:
  - Deep Tube-well,
  - Khasdi / Nadis / Tankas / Ponds / Wells / Oceanis
  - River,
  - Rivulet / Naula / Gadhera,
  - Spring,
  - Treated surface water

- The results section is broadly categorized in to two parts. The first part highlights block and district-wise distribution of natural water resources that are being harvested for fresh water supply. The second part highlights blocks and districts that are highly vulnerable as per the integrated index based estimation of water vulnerability.
• Springs (70.3%) followed by Streams (20.4%) and Rivulet / Naula / Gadhera (7.3%) are noted to be highly tapped for water schemes in Chamoli.
• The Ghaat block of Chamoli district has the highest water dependency on Springs (84%).

4.1.4 Champawat

• The common generic water sources used for water supply schemes over the districts are:
  i. Deep Tube-well,
 ii. Khadins / Nadins/ Tankas/ Ponds / Wells / Ooranis,
 iii. Infiltration well,
 iv. River,
 v. Rivulet / Naula / Gadhera,
 vi. Spring,
 vii. Treated Surface Water,
 viii. Streams

• Block-wise distribution of water sources in the Champawat district of Uttarakhand used for water supply by governmental agencies is provided in Annexure 4.
• The total number of operational water schemes in Champawat district is noted to be 1501.
• Rivulet / Naula / Gadhera (79.5%) followed by Springs (8%) and Streams (6%) are noted to be highly tapped for water schemes in Champawat.
• The Champawat block has the highest water dependency on Springs, approx. 10% of total water supply schemes is dependent directly on Springs.

4.1.5 Pauri-Garhwal

• The common generic water sources used for water supply schemes over the districts are:
  i. Deep Tube-well,
 ii. Khadins / Nadins/ Tankas/ Ponds / Wells / Ooranis,
 iii. River,
 iv. Rivulet / Naula / Gadhera,
 v. Spring,
 vi. Treated Surface Water,
 vii. Streams

• Block-wise distribution of water sources in the Pauri-Garhwal district of Uttarakhand used for water supply over the districts are:
  i. Deep Tube-well,
  ii. Shallow Tube-well,
  iii. Treated surface water

• The total number of operational water schemes in Haridwardistrict harvesting natural water resources is noted to be 1272.
• Deep Tube-well(72.2%)followed by Shallow tube-well(24.4%)and Treated surface water(2.5%)are noted to be highly tapped for water schemes in Haridwar.
• The Khanpur block has the highest water dependency on Deep tube-well, approx.78% of total water supply schemes is dependent on Deep tube-well.
• No block in the Haridwar district is found to directly harvest Springs for water supply, primarily due to unavailability of Springs at lower elevation.

4.1.6 Hardiwar

• The common generic water sources used for water supply schemes over the districts are:
  i. Deep Tube-well,
  ii. Khadins / Nadins/ Tankas/ Ponds / Wells / Ooranis,
  iii. Spring,
  iv. Stream,
  v. Khadins / Nadins/ Tankas/ Ponds / Wells / Ooranis,
  vi. Treated Surface Water,
  v. Rivulet / Naula / Gadhera

• The total number of operational water schemes in Pauri-Garhwal district harvesting natural water resources is noted to be 2053.
• Rivulet / Naula / Gadhera (50.1%) followed by Springs(24.2%) and Streams(18.1%)are noted to be highly tapped for water schemes in Pauri-Garhwal.
• The Dishat block has the highest water dependency on Springs, approx.35% of total water supply schemes in this block is directly dependent on Springs.

4.1.7 Nainital

• The common generic water sources used for water supply schemes over the districts are:
  i. Deep Tube-well,
  ii. Rivulet / Naula / Gadhera

• Other than the above mentioned generic water sources, few cases are also identified wherein water supply schemes are operational through water from Infiltration well, shallow tube-well and open-well.
• The total number of operational water schemes in Haridwar district harvesting natural water resources is noted to be 2053.
• Rivulet / Naula / Gadhera (50.1%) followed by Springs(24.2%) and Streams(18.1%)are noted to be highly tapped for water schemes in Haridwar.
• The Dishat block has the highest water dependency on Springs, approx.35% of total water supply schemes in this block is directly dependent on Springs.

4.1.8 Rudraprayag

• The common generic water sources used for water supply schemes over the districts are:
  i. Rivulet / Naula / Gadhera

• Other than the above mentioned generic water sources, few cases are also identified wherein water supply schemes are operational through water from Infiltration well, shallow tube-well and open-well.
• The total number of operational water schemes in Haridwar district harvesting natural water resources is noted to be 2053.
• Rivulet / Naula / Gadhera (50.1%) followed by Springs(24.2%) and Streams(18.1%)are noted to be highly tapped for water schemes in Haridwar.
• The Dishat block has the highest water dependency on Springs, approx.35% of total water supply schemes in this block is directly dependent on Springs.

4.1.9 Rudraprayag

• The common generic water sources used for water supply schemes over the districts are:
  i. Rivulet / Naula / Gadhera

• Other than the above mentioned generic water sources, few cases are also identified wherein water supply schemes are operational through water from Infiltration well, shallow tube-well and open-well.
• The total number of operational water schemes in Haridwar district harvesting natural water resources is noted to be 2053.
• Rivulet / Naula / Gadhera (50.1%) followed by Springs(24.2%) and Streams(18.1%)are noted to be highly tapped for water schemes in Haridwar.
• The Dishat block has the highest water dependency on Springs, approx.35% of total water supply schemes in this block is directly dependent on Springs.

4.1.10 Tehri-Garhwal

• The Augustmuni block has the highest water dependency on Springs, approx.27% of total water supply schemes in this block is directly dependent on Springs.

4.1.11 Udham Singh Nagar

• The only two dominant water sources used for water supply schemes over the districts are:
  i. Deep Tube-well,
  ii. Shallow Tube-well,

• Other than the above mentioned generic water sources, few cases are also identified wherein water supply schemes are operational through water from River, Treated surface water, canal and community collection.
• The total number of operational water schemes in Tehri-Garhwal district harvesting natural water resources is noted to be 5161.
• Rivulet / Naula / Gadhera(53.4%)followed by Springs(20.1%) and Khadins / Nadins/ Tankas/ Ponds / Wells / Ooranis(15.6%)are noted to be highly tapped for water schemes in Tehri-Garhwal.
• The Jakhandihar block has the highest water dependency on Springs, approx.45% of total water supply schemes in this block is dependent on Springs.

4.1.12 Udhampur

• Only a single cases is identified wherein water supply schemes are operational through an Open Well.
• The total number of operational water schemes in Udhampur block is directly dependent on Open Well.
• The only two dominant water sources used for water supply schemes in this block are:
  i. Deep Tube-well,
  ii. Shallow Tube-well,
• The common generic water sources used for water supply schemes over the districts are:
  i. Deep tube-well
  ii. Rivulet / Naula / Gadhera
  iii. Spring.
  iv. Khadins / Nadins/ Tankas/ Ponds / Wells/ Ooranis,
  v. Stream,
  vi. Rivulet / Naula / Gadhera (69.2%) followed
  by Springs(13.3%) and Deep Tube Well (9.7%) are noted to be highly tapped for water schemes in Dehradun.
  vii. Khadins / Nadins/ Tankas/ Ponds / Wells/ Ooranis, approximately 27% of total water supply schemes
  are dependent on Springs.
  ix. Stream,
  x. Deep tube-well
• Other than the above mentioned generic water sources, few cases are also identified wherein water supply schemes are operational through water from River, Treated surface water, Shallow well, Open well, and Canal.
• The total number of operational water schemes in Dehradun district harvesting natural water resources is noted to be 1336.
• Rivulet / Naula / Gadhera(36.7%)followed by Deep Tube Well (20.3%) and Springs(18.8%) are noted to be highly tapped for water schemes in Dehradun.
• The Chakrata block has the highest water dependency on Springs, approx.27% of total water supply schemes in this block is directly dependent on Springs.

4.2 Spatial characteristics of fresh water sources harvested for water supply schemes:
  For the entire state of Uttarakhand, a total of 41753 fresh water supply schemes were documented till 31st July, 2019 harvesting different water resources. The block-wise assessment of source wise distribution of water supply schemes indicates that except for the four low lying districts (i.e. Udham Singh Nagar, Dehradun, Haridwar and partly Nainital), most of the districts in Uttarakhand are highly dependent of natural Rivulets, Naula, Gadhera(a total of 20,051 schemes out of 41,753) and Springs(a total of 5,866 schemes out of 41,753) (Figure 3). Amongst the total of 95 blocks within Uttarakhand, a total of 54 blocks (56.8%) was found to be most dependent on Rivulet / Naula / Gadherafor piped fresh water supply. Similarly, a total of 10 blocks (10.5%) was found to be most dependent on Springs. Subsequently, any natural and / anthropogenically induced change to these very fragile water resources are anticipated to have significant impact on fresh water availability.

Moreover, concentration of fresh water supply schemes per 100,000 population was estimated for each district of the state, and Pithoragarh district followed by Chamoli (Nainital is not considered as purely hill district) were noted to have lowest concentration of schemes (425.0 and 462.0) per 100,000 population amongst the most water scarce blocks of each district of Uttarakhand is provided in Table 5. Interestingly, fresh water supply schemes in all these blocks were also noted to be highly dependent on Springs. Consequently, these blocks can be categorized as extremely vulnerable having maximum water resource threat on Springs.

4.3 Water vulnerability
  The block-wise distribution of five components of WSI, i.e. Hydrology (H), Environment (E), Life (L), Rainfall (R) and Vertical Proximity (Pri), are provided in Figure 5. It can be noted from the L index that most of the mid-Himalayan hill districts are having moderate population load where as E, R and Pri indices are having maximum vulnerability for higher mountain districts. However, due to availability of significant surface water through rivers and less population density, the higher mountainous districts were noted to have high H indices. The final Water Scarcity Indices for all the districts of Uttarakhand indicates that the low lying districts of Kumaon regions are having much lesser water scarcity than some of the mid Himalayan districts where population load along with unavailability of surface water resulting maximum water scarcity.

The Water Scarcity Indices for all the blocks of Uttarakhand further indicated that Ghata block of Chamapawat, Ramgarh block of Nainital, Garur block of Bageshwar and Pokhra block of Pauri-Garhwal were amongst the most water scarce blocks. The highest water scarce blocks of each district of Uttarakhand is provided in Table 5. Surprisingly, fresh water supply schemes in all these blocks were also noted to be highly dependent on Springs. Consequently, these blocks can be categorized as extremely vulnerable having maximum water resource threat on Springs.

Figure 3: Subplot (a) and (b) indicates district-wise distribution of most tapped and second most tapped water resources in Uttarkhand. Subplot (c) indicates district-wise comparison of total number of schemes harvesting fresh water from Rivulet / Naula / Gadhera and Springs.

Figure 4: District-wise distribution of total harvested water sources per 100,000 populations in Uttarkhand.
The major issues realized during the composition of this report related to water availability from the natural water sources used for tapped water supply are:

- Unavailability of source-wise discharge and/or extraction data
- Unavailability of current status of schemes, i.e., functional, non-functional, etc.
- Unavailability of total number of population benefitted from each scheme.

Therefore, some of the generic recommendations for sustainable usages of natural water sources of Uttarakhand should include:

- The majority of sources used for water supply in the state are either springs or spring fed rivulets and majority of these sources are showing decline in their flow. Considering this, the source centred approach of spring rejuvenation incorporating integrated bio-physical and social measures for rain water harvesting, can provide viable solutions to water sustainability of the region. One of the viable options could be development of dedicated Water Sanctuaries (Jal Abhiyan) in each villages for rejuvenating at least one perennial spring/stream based on spring sanctuary concept. Launching a mass movement for creation of well protected spring catchment with appropriate policy backup and active participation of villagers can help in achieving the water security in mountain villages within a specific time frame.
- Now several ministries and developmental agencies have accepted the concept of watershed for wasteland restorations, recharging of water sources, creating and empowering of decentralized village institutions, and strengthening of the participatory processes. The need of the hour is to dovetail water source centered approach into all watershed development projects strengthening the participatory processes. The need of the hour is to dovetail water source centered approach into all watershed development projects. The involvement of villagers can help in achieving the water security in mountain villages within a specific time frame.
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the way to sustainable management of water. Apart from inter and intra state conflicts on sharing water, agricultural, industrial and domestic uses are competing increasingly because of limited supply. Optimisation of water allocation is needed for its efficient utilisation as water requirement is closely related to population, demand for food, production of non-agricultural and industrial items, production of energy and improvement of the quality of life, and preserving the ecology of the region.

• Information sharing mechanism for water data is urgently needed. A continuous monitoring of hydro-meteorological data and consequent assessment about the ups and downs in precipitation amount and temperature rise would further help the planners in strengthening their planning and making projections for water management for future. There is also lack of well-developed meteorological and river gauging network for improving the knowledge on surface and subsurface hydrology, rainfall and sediment transport, etc. throughout the state.

• Data of Natural Springs is hardly available in the state. There is a need for launching a time bound campaign in the state for creating a GIS based inventory of the natural springs of Uttarakhand state, which will help in developing better understanding of the springs and preparation of village Spring Atlas for planning purposes.

ANNEXURES

Annexure 1: Block-wise distribution of water sources in the Almora district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
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Annexure 2: Block-wise distribution of water sources in the Bageshwar district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal

Annexure 3: Block-wise distribution of water sources in the Chamoli district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
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Annexure 4: Block-wise distribution of water sources in the Champawat district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
Annexure 5: Block-wise distribution of water sources in the Pauri-Garhwal district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
Annexure 6: Block-wise distribution of water sources in the Haridwar district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal

Annexure 7: Block-wise distribution of water sources in the Nainital district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
Annexure 8: Block-wise distribution of water sources in the Pithoragarh district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal

Annexure 9: Block-wise distribution of water sources in the Augustmuni district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
Annexure 10: Block-wise distribution of water sources in the Tehri-Garhwal district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
Annexure 11: Block-wise distribution of water sources in the Udham Singh Nagar district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal

Annexure 12: Block-wise distribution of water sources in the Uttarkashi district of Uttarakhand used for water supply by governmental agencies. Data source: IMIS portal
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