WORKING PAPER

Springs in the Godavari Landscape, Nepal

Mapping, governance, and revival

CORRESPONDING AUTHOR
Madhav Prasad Dhakal (madhav.dhakal@icimod.org)

CONTRIBUTORS
Madhav Prasad Dhakal,[1] Karishma Khadka,[1] Gunanidhi Pokhrel,[1] Jayesh Desai,[2] Christopher Kingsley,[3] Yogesh Barola,[2] and Sanjeev Bhuchar[1]

Executive summary

Godavari, situated in the southern part of Kathmandu Valley, is home to high-discharge perennial springs. Communities here depend largely on these springs for drinking, and for domestic and agricultural use.

Forty springs were mapped over an area of 23.8 km^2 in the Godavari and Chapakharka watersheds, in Lalitpur and Kavrepalanchok districts respectively, following the springshed approach. Of these forty, eleven critical springs were assessed in detail.

The types of springs found were depression springs, fracture springs, and karst springs, or a combination of these based on the geological conditions in which they occur. Some high-discharge springs are a combination of different types. Drainage density analysis indicates a greater contribution of the Godavari watershed to the base flow of its rivers than that of the Chapakharka watershed to its rivers.

These springs in the Godavari region have been under stress for varied reasons, including the in-migration of people into the region, the increasing demand for water in Kathmandu Valley, and a long-term decline in rainfall in the area. In addition, four springs in Godavari have dried up following the major earthquake of April 2015, resulting in decreased water availability for all users. In order to address these stressors and identify knowledge gaps, this study maps springs and springsheds in Godavari, identifies the recharge areas of selected springs, and recommends improved options for springshed management and spring revival. A six-step protocol for spring revival, developed by the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu and the Advanced Center for Water Resources Development and Management (ACWADAM), Pune, was used for the study.

[1] International Centre for Integrated Mountain Development (ICIMOD)
[2] Advanced Center for Water Resources Development and Management (ACWADAM)
[3] College of Natural Resource, University of California, Berkeley

Most springs are regulated and tapped by water user groups, known locally as *khanepani samities*. In Chapakharka, people also fetch water directly from the springs. Communities use multiple sources of water to satisfy their water needs. These include traditional stone taps, wells, treated jar water, water tankers, and piped water networks.

The study identified a total of nineteen water user groups and five small local water supply systems without formal water user groups. These cover approximately 11,000 households in all. The groups source water either fully or partially from the Godavari springshed. Among the twenty-four groups, fourteen are dependent on springs in the Godavari watershed. Two source water from the Godavari Khola and eight user groups are dependent on springs in the Chapakharka watershed.

Six water tanker filling stations pump water either directly from the Godavari Khola, or from the open wells adjacent to it. These stations supply 2,000–4,000 m^3 of water per day from the Godavari region.

An examination of the water quality revealed high levels of *E. coli* during the early monsoon in most springs. Total coliform was detected in most springs during the monsoon and winter seasons, implying that the quality of spring water is an issue. Physical and chemical water quality parameters were within Nepal's drinking water quality standards.

Hydrogeological assessments indicate that the recharge areas of selected springs are located within the same watershed or in multiple watersheds. This is due to the occurrence of a large synclinorium resulting in a complex structural setup with local folds and faults.

A few of the springs monitored showed an increased discharge, which could be a short-term phenomenon. According to local community perceptions, a few springs have either dried up after the earthquake of April 2015 or their discharge has decreased. Long-term trends indicate a significant decrease in annual rainfall, of about 25–30 mm/year. This is thought to be the main cause for the decline in spring discharge, but this needs further investigation.

This reduced discharge of the springs has adversely impacted water security in the region and reduced water availability for both people and other species. This study recommends the implementation of springshed management practices, including improved forest management, rainwater harvesting, and campaigns to raise awareness regarding reviving springs, to enhance the water security and socio-ecological resilience in the region. Springshed management needs to be carried out through a collaborative process involving water and forest user groups, wards of Godavari and Panauti municipalities, and other stakeholders in the region.

Keywords: *Hydrogeology, water quality, springshed management, climate change, Godavari, water user groups*

Contents

Abbreviations and acronyms

ACWADAM	Advanced Center for Water Resources Development and Management, Pune
DFAT	Department of Foreign Affairs and Trade, Government of Australia
DHM	Department of Hydrology and Meteorology, Government of Nepal
DO	Dissolved oxygen
DWS	Drinking water supply
EC	Electrical conductivity
GKP	Godavari Knowledge Park
GPS	Global Positioning System
HI-AWARE	The Himalayan Adaptation, Water and Resilience consortium
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
KII	Key informant interview
KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
NDWQS	Nepal Drinking Water Quality Standards
NWCF	Nepal Water Conservation Foundation
SDIP	Sustainable Development Investment Portfolio
TDS	Total dissolved solids
VDC	Village Development Committee
WLE	Water Land and Ecosystem project
WUGs	Water user groups

Acknowledgements

The authors would like to acknowledge the efforts and contributions of many people who have been involved in this research. We would like to express our deep gratitude to Arun Bhakta Shrestha for his support in the review of this paper and continuous encouragement towards its publication. Our deep gratitude to Aditi Mukherji for initiating, coordinating, and providing overall supervision of the study. A special thanks to Himanshu Kulkarni of the Advanced Center for Water Resources Development and Management (ACWADAM), Pune, for coordinating and supervising the study.

We are thankful to Samden Sherpa Lama for overall coordination during the field trips and data collection, Rajendra Shrestha for the geological surveys and his inputs in the hydrogeological analysis, and Santosh Nepal, Vishwas Sudhir Chitale, and Saurav Pradhananga for providing data and information.

Furthermore, we would like to acknowledge Jeevan Tamang, Purna Tamang, and Ram Bahadur Tamang for the collection of the bimonthly spring data. Our special thanks to Nabina Lamichhane and Arnav Upadhyay for assistance in carrying out the social survey.

This study was undertaken under the DFAT Brahmaputra and Energy Special Project of the International Centre for Integrated Mountain Development (ICIMOD) through the Sustainable Development Investment Portfolio (SDIP), supported by the Department of Foreign Affairs and Trade (DFAT), Government of Australia. It was partially supported by the core funds of ICIMOD, contributed to by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Switzerland, and the United Kingdom.

SECTION I

Introduction

1.1 Background

Groundwater, in the form of springs, is a vital source of water for millions of people in the mid-hills of the Hindu Kush Himalaya (HKH) region. Mountain springs constitute a very reliable and sustainable source of freshwater, meet human requirements, improve livelihoods, and maintain a balance in the ecosystem. Springs are an important contributor to riverine base flows in the mid-hills of the HKH. They also have a huge cultural significance for mountain communities (NITI Aayog, 2018; Scott et al., 2019).

Though the Himalaya are the source of numerous perennial rivers, communities in the hills and mountains largely depend on springs to meet their water needs. A reduction in spring discharge is being experienced across the HKH, as a result of which communities in the region are facing unprecedented water stress (Negi and Joshi, 2002; Tambe et al., 2012; Valdiya and Bartarya, 1989). While there is abundant water for communities during the monsoon season, water scarcity is a common problem during the dry period, exacerbated by changing precipitation patterns attributed to climate change (Gentle and Maraseni, 2012; Malla, 2009; Merz et al., 2003; Tiwari and Joshi, 2015). Other natural and anthropogenic causes for springs drying up include land use changes, deforestation in the upper catchments, seismic activity (earthquakes), and infrastructure development such as road construction, tunnelling, etc (Gisbert et al., 2009; John et al., 2017; JVS and GWP, 2017; Negi and Joshi, 2002; Sharma et al., 2016; Vincenzi et al., 2009).

In response to this deterioration of springs and changing context, the International Centre for Integrated Mountain Development (ICIMOD), through its innovation fund, and later through the Koshi Basin Initiative, piloted a springs and ponds project in Kavrepalanchok district in 2013, together with the Nepal Water Conservation Foundation (NWCF). Subsequently, the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI), the Water Land and Ecosystem (WLE), and the Himalayan Adaptation, Water and Resilience (HI-AWARE) projects implemented springshed activities in pilot sites in the Khar village development committee (VDC), two pilot sites in Dailekh and Sindhupalchok districts, and a pilot site in Nuwakot district of Nepal respectively. WLE also initiated pilot projects in Nainital, and HI-AWARE implemented spring revival activities in Kalimpong, both in India (Sharma et al., 2016; Sharma et al., 2019; Siddique et al., 2019).

Based on the learnings from these projects, ICIMOD and ACWADAM, Pune developed a six-step protocol for spring revival in the HKH (Shrestha et al., 2018). A comprehensive methodology was developed for research and practice on reviving springs in the HKH region. The methodology was followed in three districts of Bhutan and in Godavari to study and revive springs through the Sustainable Development Investment Portfolio (SDIP), Government of Australia.

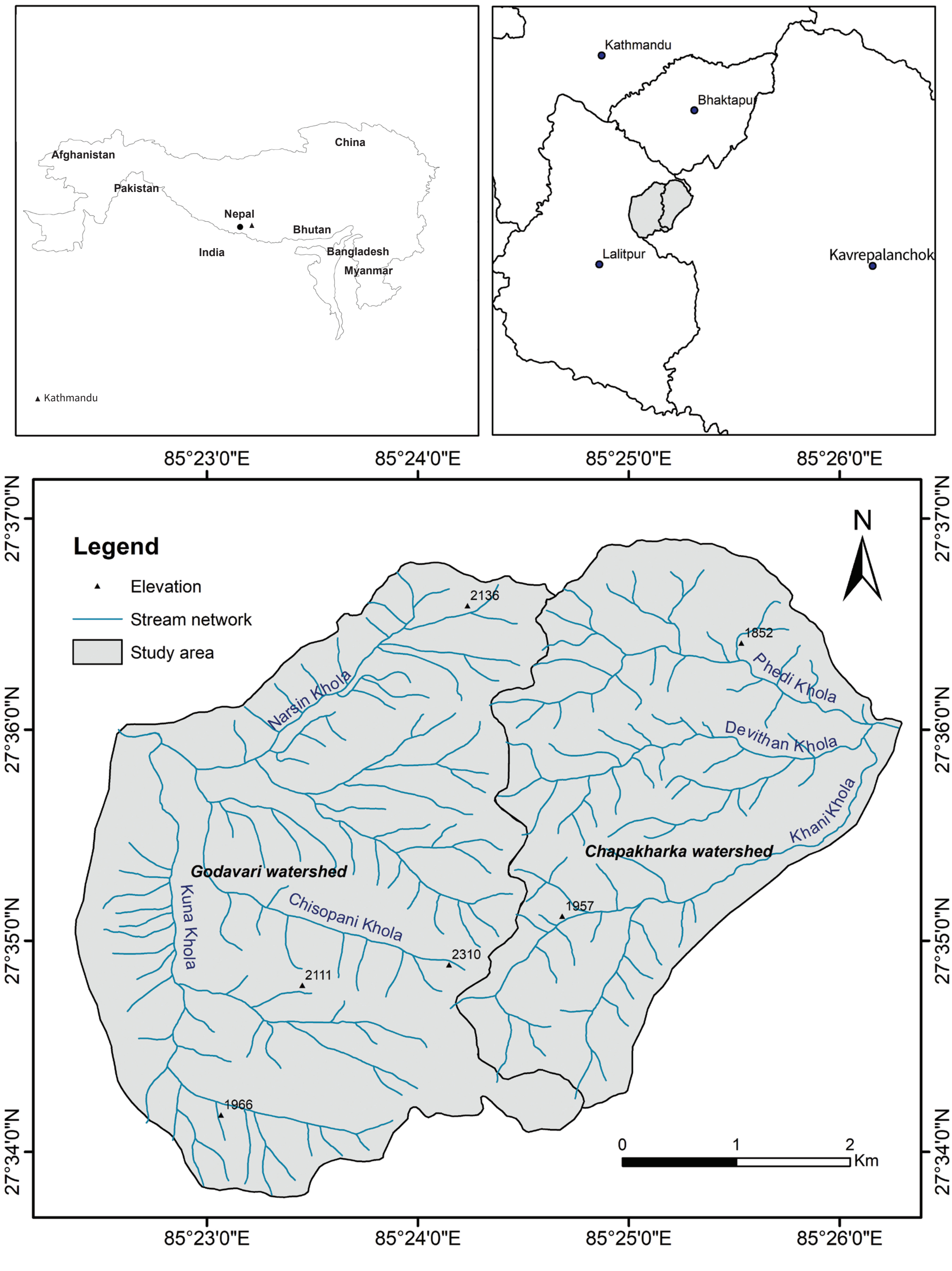
There has been an abrupt increase in the demand for water in the Kathmandu Valley, due to the rising population and the spread of industries, which has led to a heavy exploitation of groundwater resources. The annual demand for water in Kathmandu has increased from 35.1 million liters per day (MLD) in 1988 to 155 MLD in 2000 to 320 MLD in 2009 to 370 MLD n 2015 (Thapa et al., 2016). The high rate of groundwater abstraction from shallow aquifers and reduced flows from springs has put tremendous pressure on deep aquifers.

Springs are also an essential source of drinking water in the peripheral, hilly areas of cities such as Kathmandu. Godavari, which is situated in the southeastern part of Kathmandu Valley, has a large number of high-discharge perennial springs. Groundwater also occurs here in the form of wetlands. The springs in Godavari are the major source of water not only for the people here but also important for the downstream populations in the valley.

1.2 Study area

The study area is located in Godavari municipality in Lalitpur district and Panauti municipality in Kavrepalanchok district in the southeastern part of Kathmandu Valley (Figure 1). The Godavari Khola (river), which flows from south to north, contributes to the Hanumante Khola, one of the tributaries of the Bagmati River. The major tributaries in the area are the Kuna Khola, Chisopani Khola, Sungure Khola,

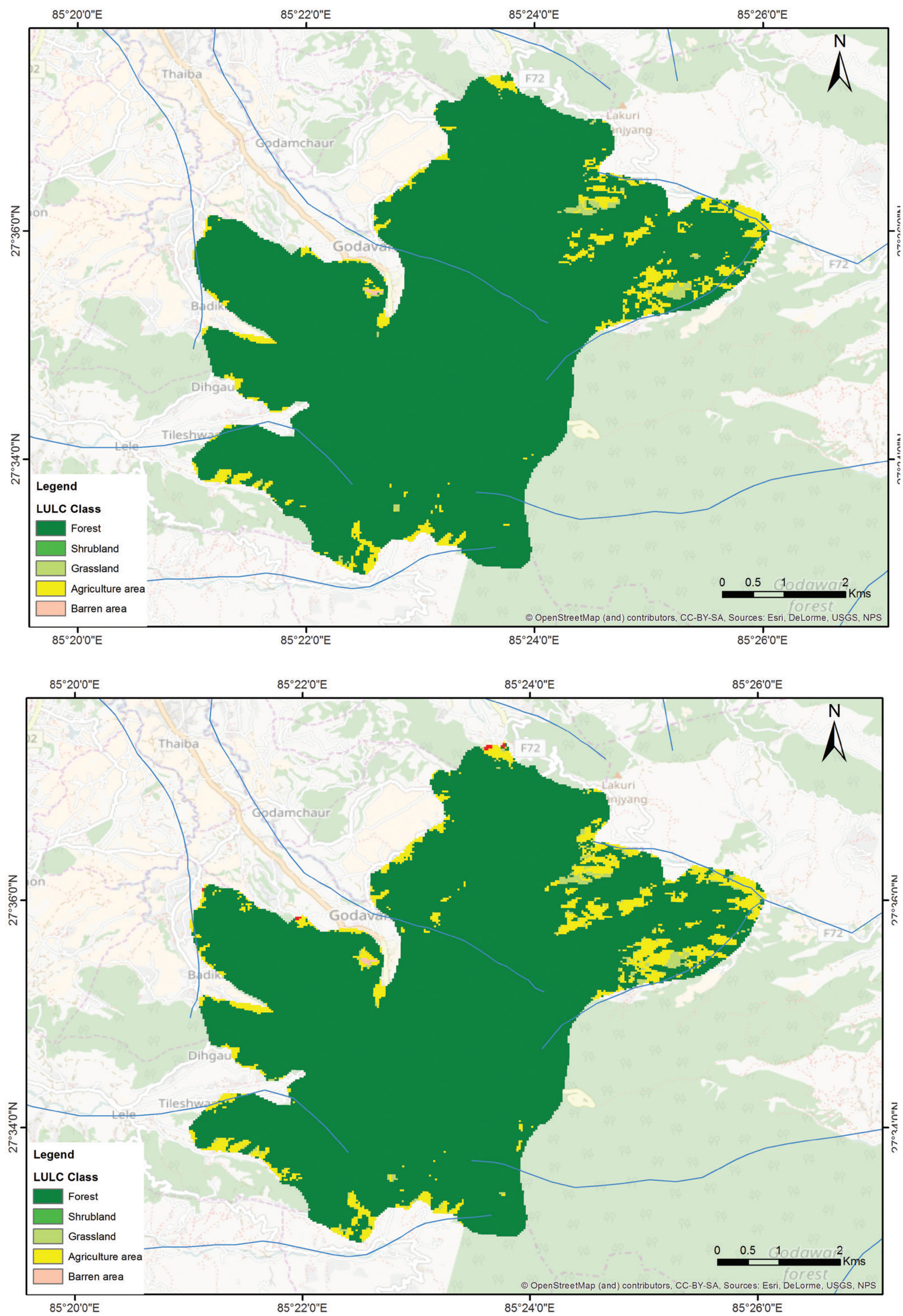
FIGURE 1 LOCATION MAP OF THE STUDY AREA



and Narsin Khola in the Godavari watershed in Lalitpur district, and Khani Khola, Devithan Khola, and Phedi Khola in the Chapakharka watershed in Kavrepalanchok district. The study area spans an elevation range from roughly 1,500 metres above mean sea level (masl) in the valley to about 2,700 masl at Phulchowki. It covers 23.8 km^2.

The study area includes the Godavari Knowledge Park (GKP), located on the southern slopes of Kathmandu Valley in Lalitpur district, covering an area of 30 hectares. The Godavari Landscape (Chapakharka and Godavari watersheds) presents a rich mosaic of land use systems providing multiple ecosystem services. Forests constitute the dominant land use system in the landscape, covering about 31.5 km^2, followed by grasslands at 2.5 km^2 in 2010. However, there has been a slight decline in forest cover here – between 1990 and 2010 – due to an increase in grasslands, agricultural land, and the built-up area (Figure 2). Forest cover

FIGURE 2 LAND USE AND LAND COVER IN THE GODAVARI LANDSCAPE IN 1990 (TOP) AND 2010 (BOTTOM)



has improved gradually since 1994 when forest management was handed over to local communities.

1.3 Objectives of this study

The major objectives of this study are to understand the status and issues of spring water resources, analyse the social and governance issues related to springs, identify the critical springs that require intervention, and support springshed management in the region. Within these broad objectives, the specific objectives of the study are to:

- Map the springs and other surface water bodies in the study area
- Study the area's geology and hydrogeology
- Understand the institutional and governance systems for managing springs in the area
- Study the quantity and quality of spring water including its potability
- Identify the potential recharge areas of springs, based on the hydrogeology of the area
- Recommend measures to the municipalities and other potential stakeholders for conservation of the springshed

SECTION II

Methodology

The springshed of a particular spring (or set of springs) is the area from its point of recharge to its point of discharge. It includes the aquifer, which can be located in one or multiple watersheds, which integrate to supply water to a group of springs. The springshed management approach includes a hydrogeological survey to identify the storage and movement of water in the aquifer, and the strategic recharge area of a spring. The area is then targeted for protection, in order to augment spring recharge. The methodology for this study is part of a six-step protocol that has been developed for reviving springs and springshed management in the HKH (Figure 3) (Shrestha et al., 2018). The action research part of the protocol (Steps 1–4) is presented and discussed in this working paper.

Springshed mapping in the study area commenced in 2017 with a field survey of springs and a study of rock types and structures around the springs by employing a transect walk that covered the entire area. All the springs in the study area were mapped using the Global Positioning System (GPS). A spring inventory map of the area was then prepared using Google Earth. A drainage density analysis was carried out to calculate the contribution of watersheds to the base flows of streams in the study area. We determined, through interviews, which springs were seasonal, and which ones perennial. Preliminary socioeconomic and related information was also collected, particularly regarding the nature of the water distribution system (whether piped or non-piped), the uses of spring water, and the number of dependent households.

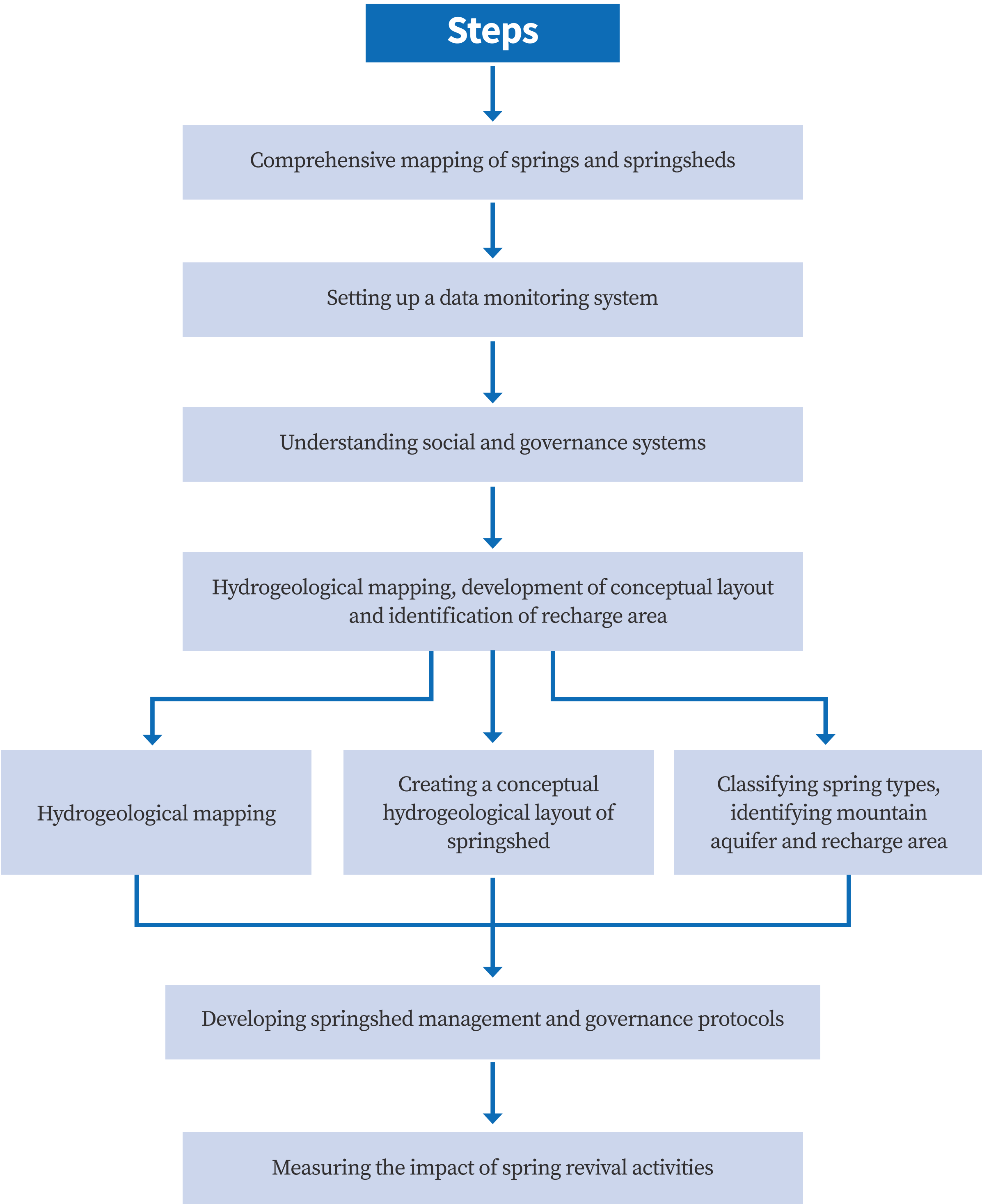
After the comprehensive springshed mapping, 11 springs – Thulo Seem, Chisopani, Sungure Khola 1, Sungure Khola 2, Godavari Kunda, Naudhara, Kuna Khola 1, Kuna Khola 2, Devithan, Khalte and Tripyani) – were selected, following a springshed approach, for long-term monitoring of spring discharge, precipitation, and water quality, based on the dependence of households on springs and the location of the springs (in the Godavari and Chapakharka watersheds). Fortnightly discharge and water quality and key parameters (electrical conductivity, total dissolved solids, salinity, and temperature) of the water in the 11 springs was measured from mid-2017 to 2019. Local resource persons were trained to collect the data. Daily rainfall data was gathered from the existing meteorological station in the GKP located at an altitude of 1,634 masl. Hydrographs were prepared with long-term data to understand spring behaviour and the aquifer system. (This data can be used to measure the impacts of spring revival activity as well.)

The water of the 11 monitored springs was tested thoroughly during the pre-monsoon and post-monsoon seasons, in June 2018 and January 2019. The water was evaluated for its potability by comparing the measured physical, chemical, and microbiological parameters – electrical conductivity (EC), total dissolved solids (TDS), acidity levels (pH), dissolved oxygen (DO), turbidity, total hardness, calcium levels (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), chloride (Cl^{-}), nitrates (NO_3^{-}), fluoride (F^{-}), cyanide (CN^{-}), ammonia (NH_3), aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), zinc (Zn), iron (Fe), mercury (Hg), *E. coli* and total coliform – with Nepal's drinking water quality standards (NDWQS, 2005).

A geological map and geological cross-sections were prepared through a detailed study of rock and rock structures in the area. A conceptual hydrogeological layout was developed for the 11 selected springs to demarcate their recharge zones.

To thoroughly map current water use patterns, and understand the institutional and governance systems in place for managing springs, key informant interviews (KIIs) were conducted with the chairpersons/vice-chairpersons of 19 WUGs and local people from the five small water supply systems that use water from the Godavari springshed. The questions pertained to physical infrastructure, water treatment, water rationing, the tariff structure, history, and plans for maintenance or future expansion. With this, the WUGs that operate around the headwaters of Godavari Khola were identified and a map of water distribution networks in the area was created with GIS mapping.

FIGURE 3 **SIX-STEP PROTOCOL FOR SPRING REVIVAL AND SPRINGSHED MANAGEMENT IN THE HKH**



Source: Shrestha et al. (2018)

SECTION III

Results

3.1 Step 1: Comprehensive mapping of springs and springsheds

The mapping of springs in the Godavari springshed generated comprehensive information about the springshed, including the location of springs, their status (whether they are dry, seasonal, or perennial), and basic geological and socioeconomic information. Spring discharge and water quality were also measured. The results are described in detail in the sub-sections that follow.

3.1.1 Spring inventory

Godavari is a repository of a large number of high-discharge, perennial springs. Groundwater occurs in the form of springs and wetlands. The springs in the Godavari watershed contribute to the base flows of the Godavari Khola, making it perennial in nature. The springs in Chapakharka watershed contribute to Bebar Khola.

During the spring inventory carried out in June 2017, 40 springs, variously located at altitudes between 1,518–2,038 m, were identified in the study area (Figure 4, Annex 1). Among them, four springs – GKP-02, Hiuende, Devithan 2, and GKP-18 – have dried out completely following the earthquake of April 2015, one was told during interactions with local people. The spring types found here are depression springs, fracture springs, and karst springs, or a combination of these, depending on the geological conditions in which they occur. Few high-discharge springs are karstic in nature.

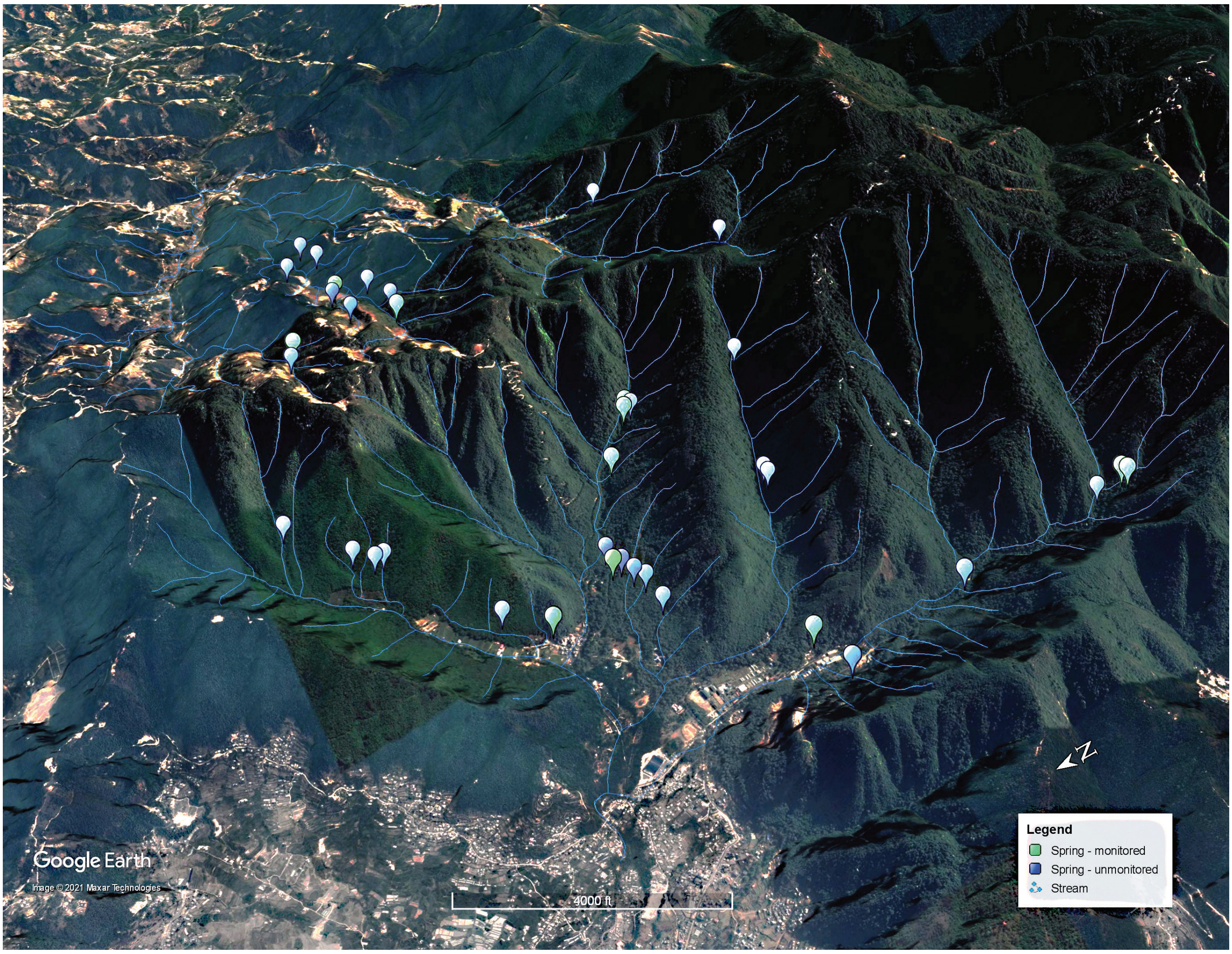
Spring water is used for drinking, domestic use, and irrigation, providing water security to households in the Godavari area. It is also used for gardening in the herbarium and botanical garden. It is also supplied to inhabitants further downstream in the Kathmandu Valley, through municipal water pipelines, water tankers, and as jar water. Some springs, such as Godavari Kunda and Naudhara, have a huge religious and cultural significance for the local people. A majority of the springs are tapped and controlled by WUGs, known locally as *khanepani samities*. The larger WUGs here are the Godavari WUG, Thaiba WUG, Harisiddhi WUG, and Chapakharka WUG, which tap most of the high-discharge springs and regulate water in the region.

Godavari Kunda, Naudhara, Devithan, Thulo Seem, Sungure Khola 1, Sungure Khola 2, Kuna Khola 1, and Kuna Khola 2 have a comparatively high discharge. The local people said that six springs, namely GKP-2, GKP-12 (Hiuende), GKP-14 (Devithan 2), GKP-18, GKP-23 (Tripyani), and GKP-31 (Gauri Kunda) were adversely affected by the April 2015 earthquake. Tripyani resumed flowing after three months of dormancy, but its discharge was highly reduced compared to before the earthquake. Gauri Kunda became seasonal and with highly reduced discharge. Hiuende, a high-discharge perennial spring tapped by the Thaiba and Harisiddhi WUGs, stopped flowing after the earthquake, due to which these WUGs have had to tap other springs in the system to meet the increasing water demand in the area. Locals also said that the discharge of many other springs reduced after the earthquake.

3.1.2 Geological mapping

Groundwater storage and movement are controlled by the nature of rocks (rock type and characteristics), their inclination (dip and strike), and rock structure (fractures and faults). Conducting geological mapping

FIGURE 4 DISTRIBUTION OF SPRINGS IN THE STUDY AREA



is important in order to understand the types and characteristics of rocks that are available in the area and in identifying recharge areas for springs. Based on rock type, structure, and inclination, recharge areas can be identified, where recharge interventions can be undertaken to increase spring flows. In terms of its geological setting, the study area lies in the Lesser Himalayan Zone of central Nepal (Figure 5). The dominant rock types found here are dolomite, slate, sandstone, and limestone that belong to the Phulchowki Group.

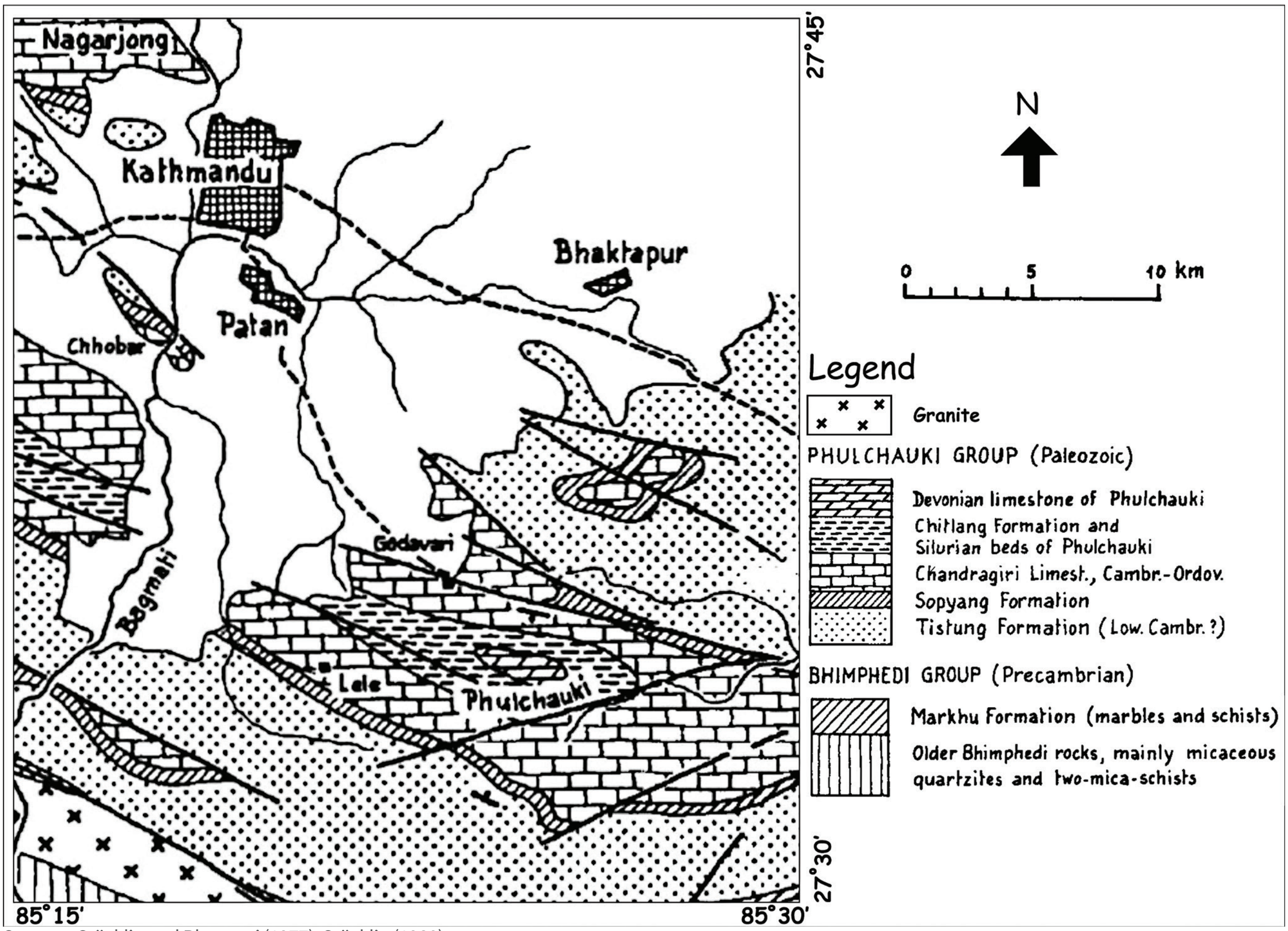
The stratigraphic subdivisions of the Phulchowki Group of the Kathmandu Complex are presented in Table 1.

TABLE 1 STRATIGRAPHIC SUBDIVISIONS OF THE PHULCHOWKI GROUP OF THE KATHMANDU COMPLEX

Unit	Main lithology	Approximate thickness (m)	Period/Era
Phulchowki Group			
Godavari Limestone	Limestone, dolomite	300	Devonian
Chitlang Formation	Slate	1,000	Silurian
Chandragiri Formation	Limestone	2,000	Cambro-Ordovician
Sopyang Formation	Slate, calcareous phyllite	200	? Cambrian
Tistung Formation	Metasandstone, phyllite, slate	3,000	? Early Cambrian -? Neoproterozoic

Sources: Stöcklin and Bhattarai (1977); Stöcklin (1980)

FIGURE 5 REGIONAL GEOLOGY OF GODAVARI REGION



Sources: Stöcklin and Bhattarai (1977); Stöcklin (1980)

Stratigraphically, dolomite and limestone, belonging to the Godavari Limestone, form the summit of the Phulchowki hill, underlain by rocks belonging to the Chitlang Formation. This formation consists mainly of dark and weathered slate interbedded with quartzite. The Chitlang Formation is underlain by limestone belonging to Chandragiri Limestone and is a prominent formation within the Phulchowki Group. Chandragiri Limestone is underlain by the Sopyang Formation, which consists of slate and calcareous phyllite. This is underlain by the Tistung Formation, the oldest unit of the Phulchowki Group. It consists of metasandstone interbedded with phyllite and slate.

The Himalaya exhibit high relief, with complex geological systems that play a vital role in the formation of mountain aquifers. Due to discontinuities in rock formations because of conditions imposed by the terrain and the structural setting, aquifers in the Himalaya are either local in extent or extend across multiple watersheds. The Godavari springshed boundary is defined based on this understanding and the prevailing geological setting in the study area (Figure 6). The springshed boundary takes into account both the Godavari and Chapakharka watersheds, which are separated by a ridge trending in the north–south direction. The rocks are generally dipping southwest (230°), with the dip amount varying between 50°–70°. A few rocks, especially at higher elevations, are found to dip towards the northeast (40°) with strikingly gentle dips of 20°–30°, which indicate a synclinal structure.

The entire Godavari region forms a large synclinorium resulting in a complex structure. Due to this, there is a lot of local folding and faulting across the entire Godavari region. A more detailed geological map at a local scale was prepared, which is critical in identifying the recharge areas of springs (Figure 7).

The Sandstone Unit, which lies to the northeastern side of the springshed, comprises interbedded limestone and marl, whereas the Limestone Unit comprises interbedded quartzite and marl. The dolomite present in the Phulchowki ridge possibly forms the core of the regional syncline, with the fold axis trending in the northwest–southeasterly direction. The cross-section in Figure 8 provides a glimpse of the geology of the Godavari springshed.

FIGURE 6 THE GODAVARI SPRINGSHED WITH THE LOCATION OF SPRINGS

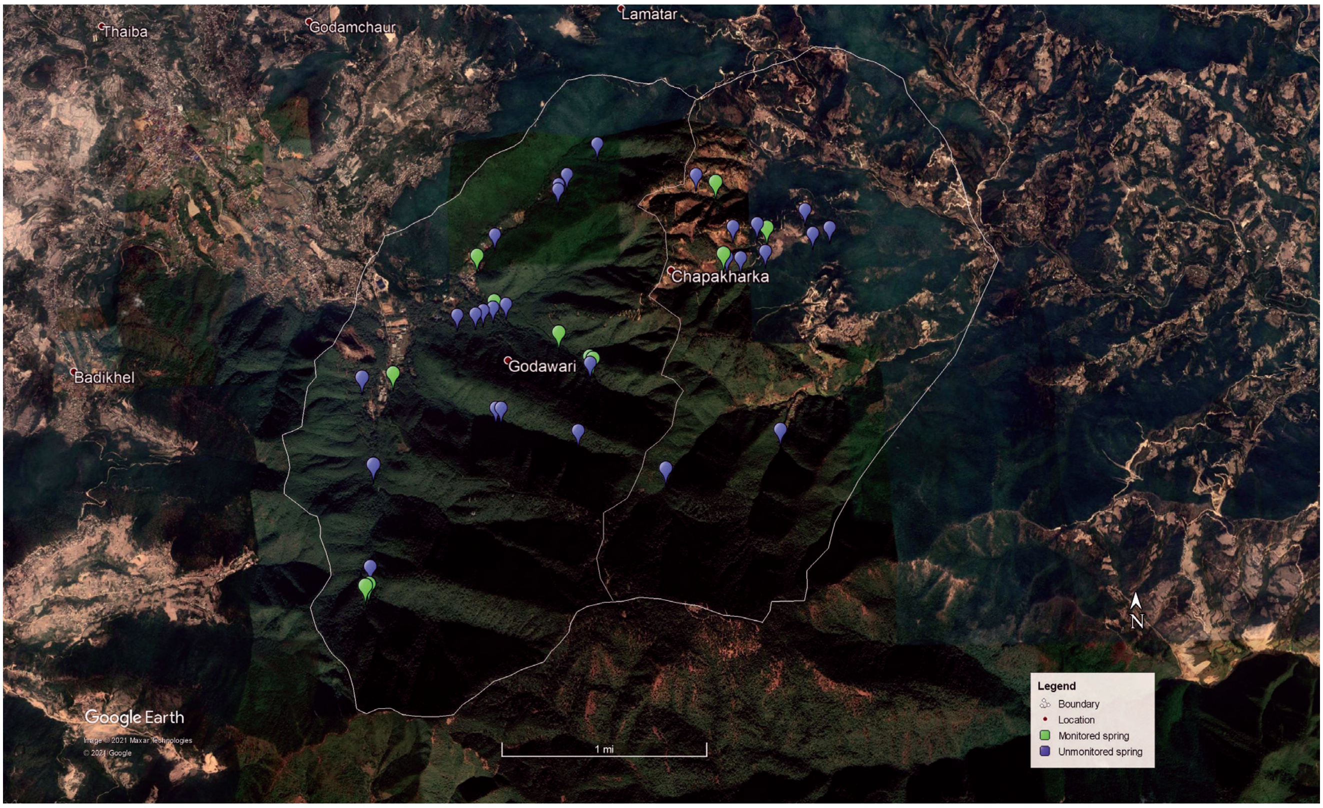


FIGURE 7 GEOLOGY OF THE GODAVARI SPRINGSHED

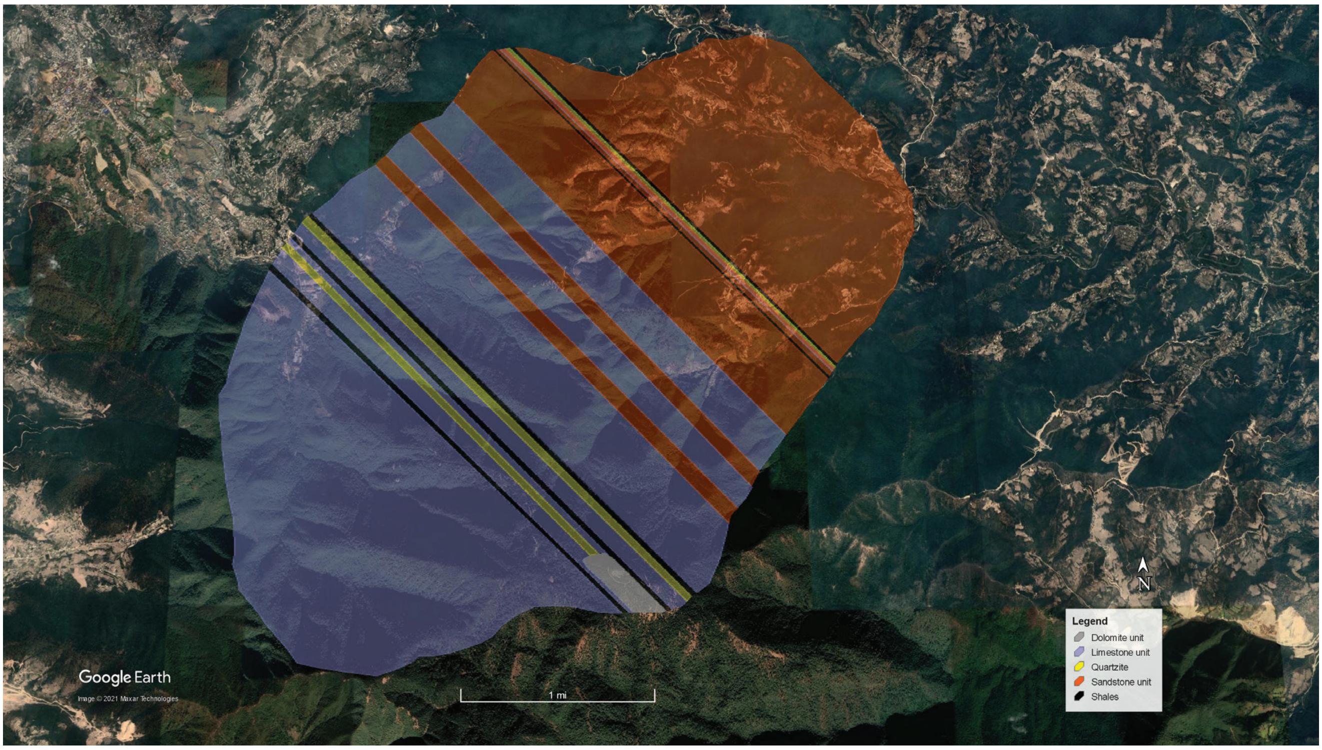
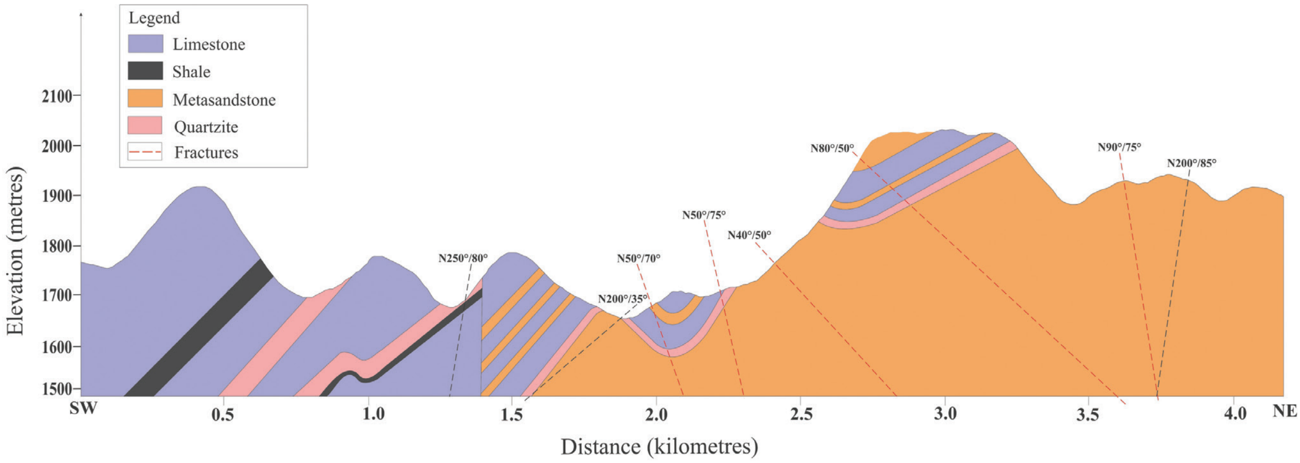


FIGURE 8 GEOLOGICAL CROSS-SECTION OF THE GODAVARI SPRINGSHED



3.1.3 Contribution of watersheds to the stream network

The Godavari and Chapakharka watersheds are separated by a ridge. The Godavari watershed drains to the west of the ridge (in Lalitpur district) whereas the Chapakharka watershed drains to the east (in Kavrepalanchok district) (Figure 9). The drainage system in the Godavari watershed is sculpted by four major streams, namely Kuna Khola, Chisopani Khola, Sungure Khola, and Narsin Khola. The Chapakharka watershed hosts three major streams, namely Khani Khola, Devithan Khola, and Phedi Khola. Both watersheds host fifth-order streams (which flow at the rate of 1–10 litres/second) as the highest order of stream. Drainage density, one of the most important morphometric characteristics of a watershed, is an indicator of the base flow of rivers (Trainer, 1969). The drainage density of the Godavari watershed is less than that of the Chapakharka watershed, indicating the prospects for a good infiltration rate due to the presence of permeable strata. The drainage density analysis found that the Godavari watershed contributes more to the base flows of its streams than the Chapakharka watershed does to its respective streams.

3.2 Step 2: Setting up a data monitoring system

Long-term rainfall data, spring discharge data, and water quality information were collected in order to understand spring behaviour and characteristics of the aquifer. Spring data is also essential in measuring the impact of spring revival activities after recharge measures are undertaken (Step 6 of the spring revival protocol). The results of the data collected from 2017 to 2019 are presented in the following subsections.

3.2.1 Spring discharge

Of the eleven springs selected for regular monitoring, bimonthly discharge and water quality was measured for eight springs in the Godavari watershed and three springs in the Chapakharka watershed (Figure 10).

Monitoring the spring discharge is important to see if there has been any significant change in discharge over time, and in particular to assess the impacts of spring revival activities. Discharge data has been analysed for two-and-a-half years, from July 2017 to December 2019. Rainfall data was collected daily at the one station at an elevation of 1,634 metres, in the Godavari Knowledge Park maintained by ICIMOD.

The data shows that annual precipitation was 1,441 millimetres (mm) in 2017, 1,715 mm in 2018, and 1,858 mm in 2019. A majority of the monitored springs show an increasing trend in discharge. Sungure Khola shows a slight decreasing trend, possibly due to an underestimation of its total flow, arising from the fact that wild boar frequently disturb the spring's flow path by diverting its channel. The most significant increase in discharge has been observed in Tripyani Khola, whose discharge reduced a lot after the 2015 earthquake. Of the 11 monitored springs, continuous data are available only for six (Thulo Seem, Sungure Khola 1, Sungure Khola 2, Devithan, Khalte, and Tripyani). Their hydrographs are presented in Figure 11.

The data reveals that the spring discharge is the highest during July, August, and September due to monsoon precipitation. Godavari Kunda, Naudhara, Kuna Khola, and Devithan have a comparatively high discharge (above 500 litres per minute) during the monsoon.

The increase in spring discharge in the last two years could be due to the increase in annual precipitation in

FIGURE 9 THE TWO WATERSHEDS WITH THE LOCATION OF SPRINGS

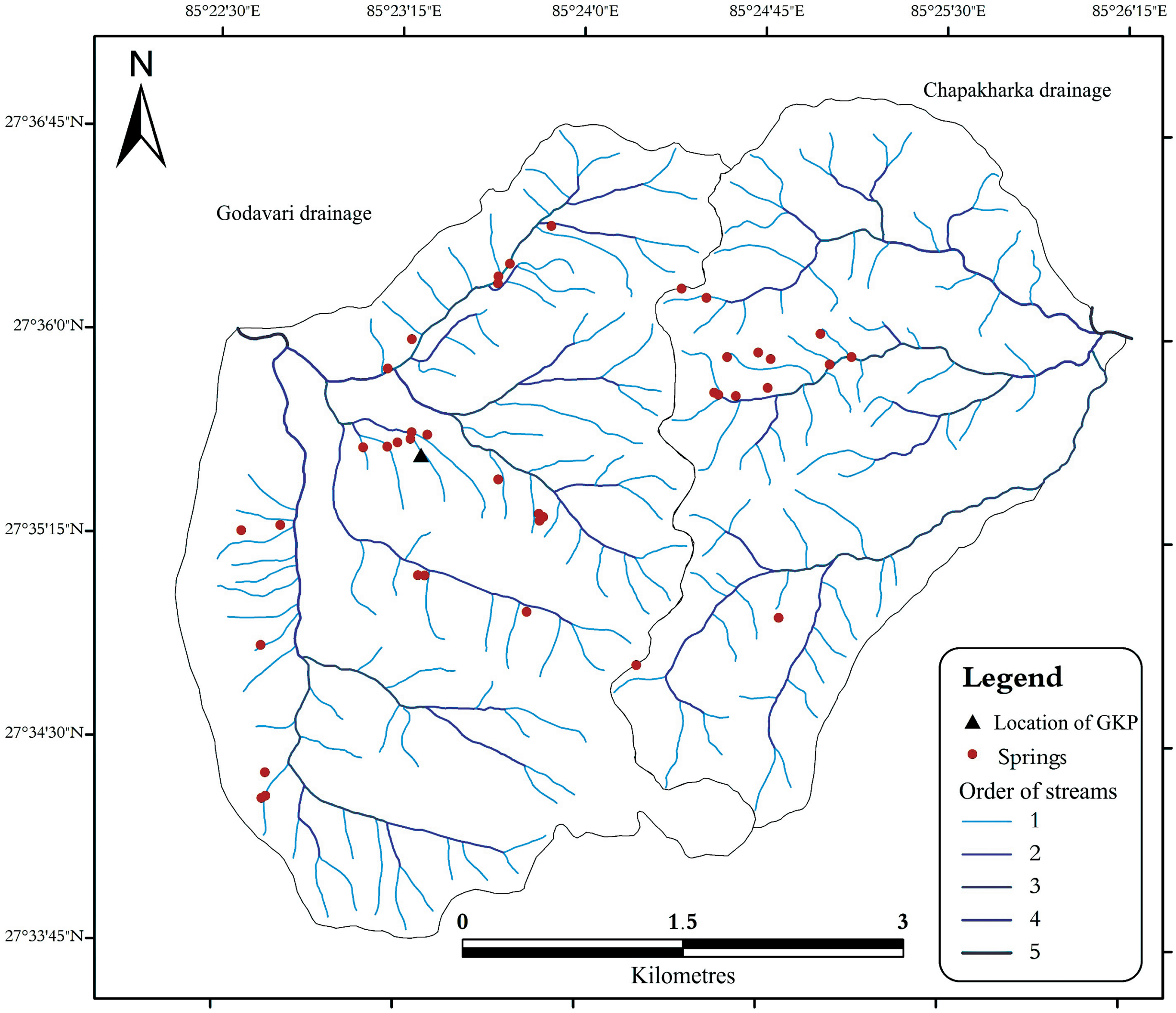
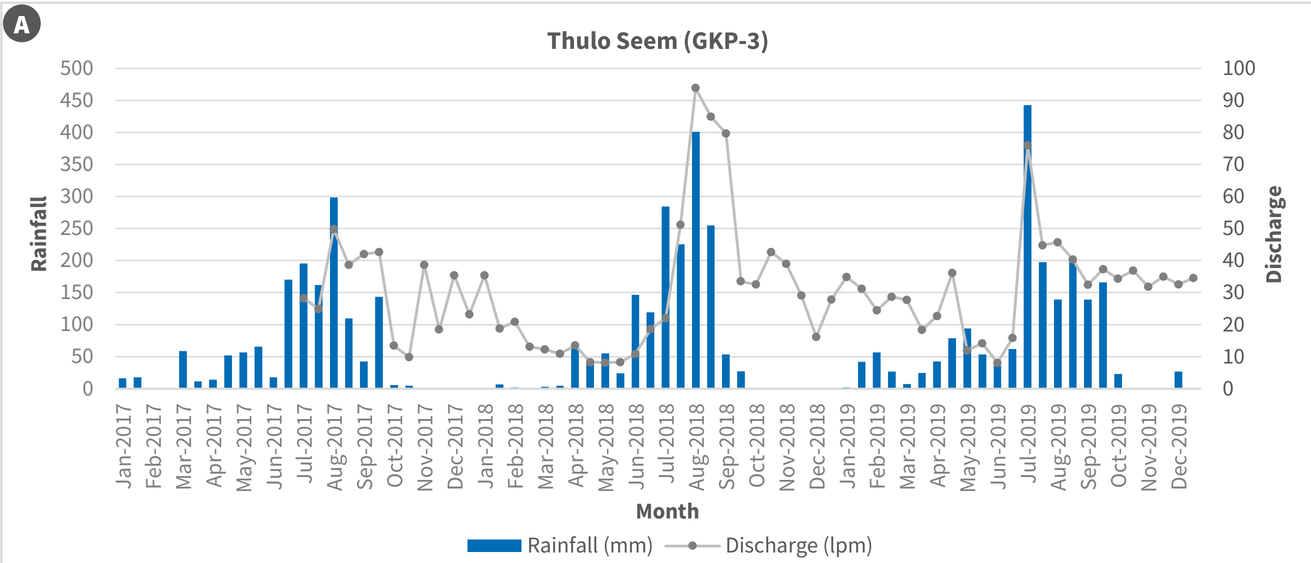
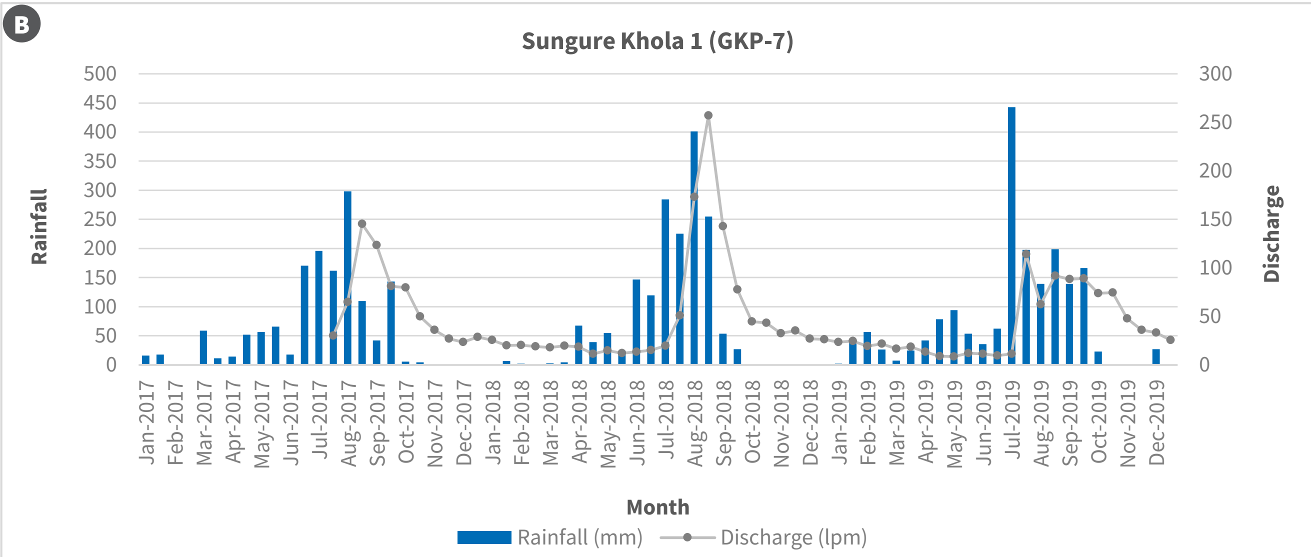
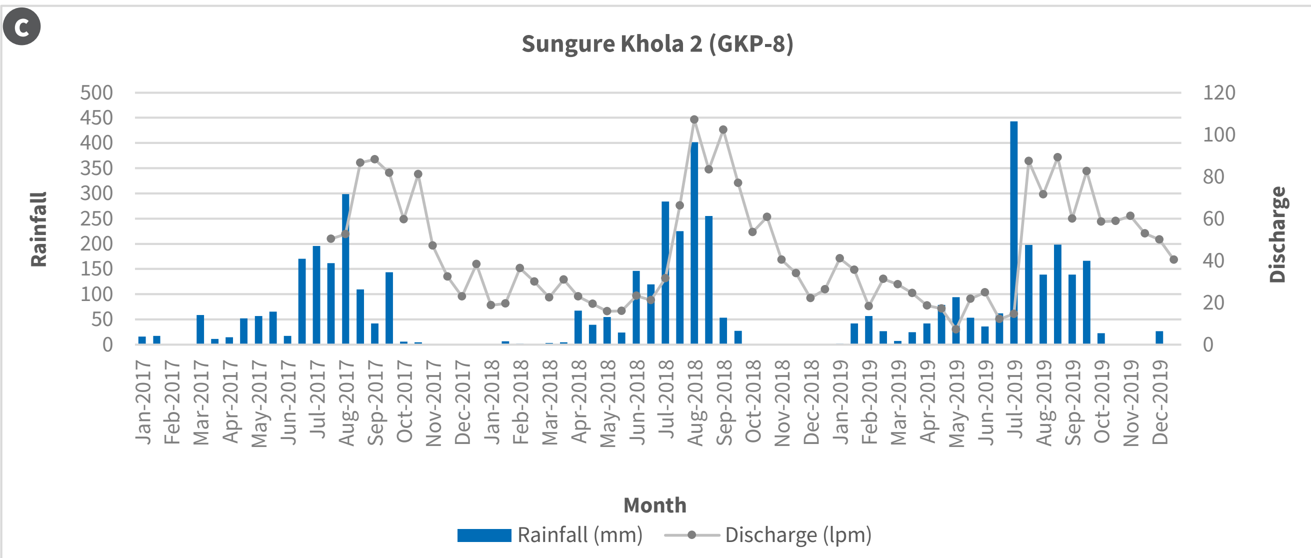


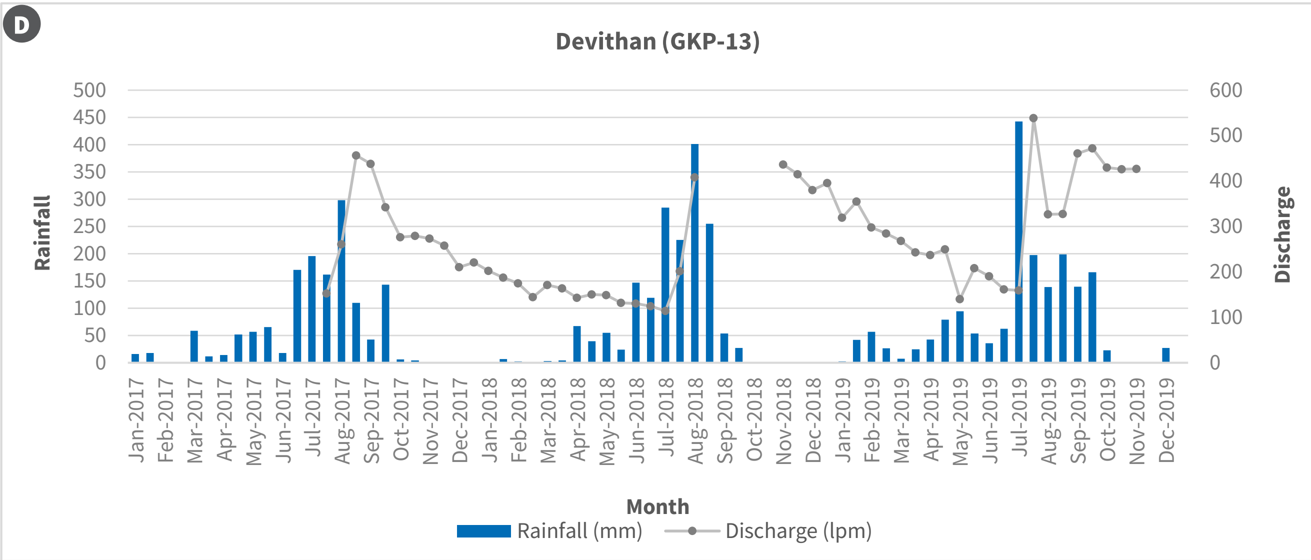
FIGURE 10 THE ELEVEN MONITORED SPRINGS IN THE STUDY AREA

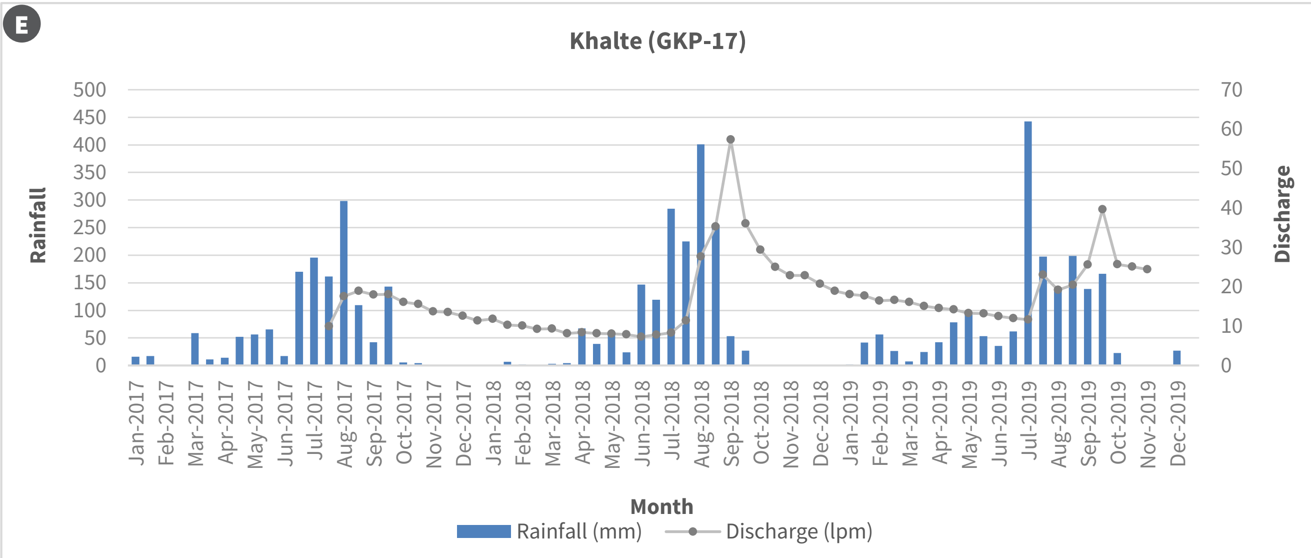
FIGURE 11 HYDROGRAPHS OF SIX MONITORED SPRINGS (A-F)

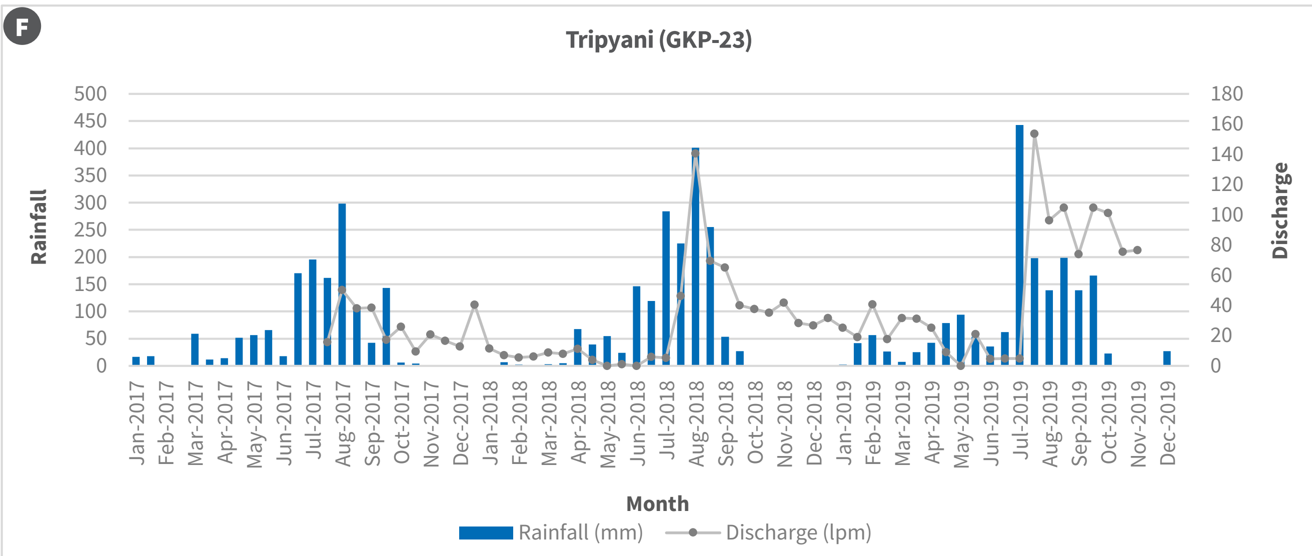







D
Devithan (GKP-13)
Rainfall
Discharge
Month
Rainfall (mm)
Discharge (lpm)


E
Khalte (GKP-17)
Rainfall
Discharge
Month
Rainfall (mm)
Discharge (lpm)

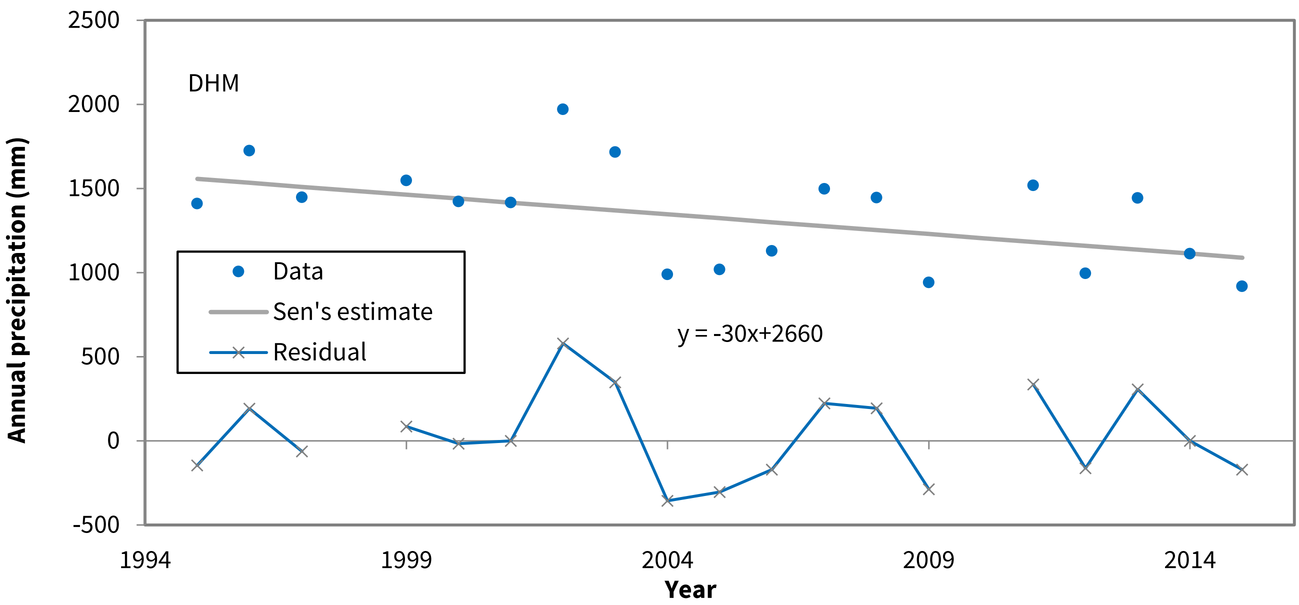

F
Tripyani (GKP-23)
Rainfall
Discharge
Month
Rainfall (mm)
Discharge (lpm)

2018 and 2019. However, long-term precipitation data for over 25 years collected by ICIMOD shows that there has been a significant decrease in rainfall, of about 25 mm a year on average over 1995–2019. Data from the Department of Hydrology and Meteorology (DHM), Government of Nepal, for 1995–2015 corroborates this decreasing trend. Their data shows a decline of 30 mm over this period (Figure 12). This decline in rainfall may be the key cause for the reduced spring discharge, which participants mentioned during KIIs, as precipitation is the most important input for recharging springs. The increase in both rainfall and spring discharge over the last two years could be a temporary phenomenon. Additionally, the relationship between climate change and spring discharge needs to be further validated through scientific enquiry, taking into account land use and land cover changes, and surface and groundwater extraction patterns over the years. Rising temperatures, greater rates of evaporation, more erratic rainfall patterns, and the changing nature of precipitation (intensity and duration) need to be validated as well.

3.2.2 Spring water quality

Fortnightly monitoring of in situ physical and chemical parameters (electrical conductivity, total dissolved solids, salinity, and temperature) of nine monitored springs has been carried out since mid-2017. The average data for two years is presented in Table 2. There was a slight decrease in their values in 2019, likely because rainfall was higher in 2019 than in 2018. The significant groundwater recharge and a reduced residence time of groundwater, resulted in lowered dissolved ion levels in 2019 (Pokhrel and Rijal 2020; Khadka and Rijal 2020). Inter-annual variation was also observed in the values due to the variation in rainfall.

FIGURE 12 PRECIPITATION TRENDS AT GODAVARI, AT ICIMOD'S GKP STATION, 1995–2019 (TOP) AND AT THE DHM STATION, 1995–2015 (BOTTOM)



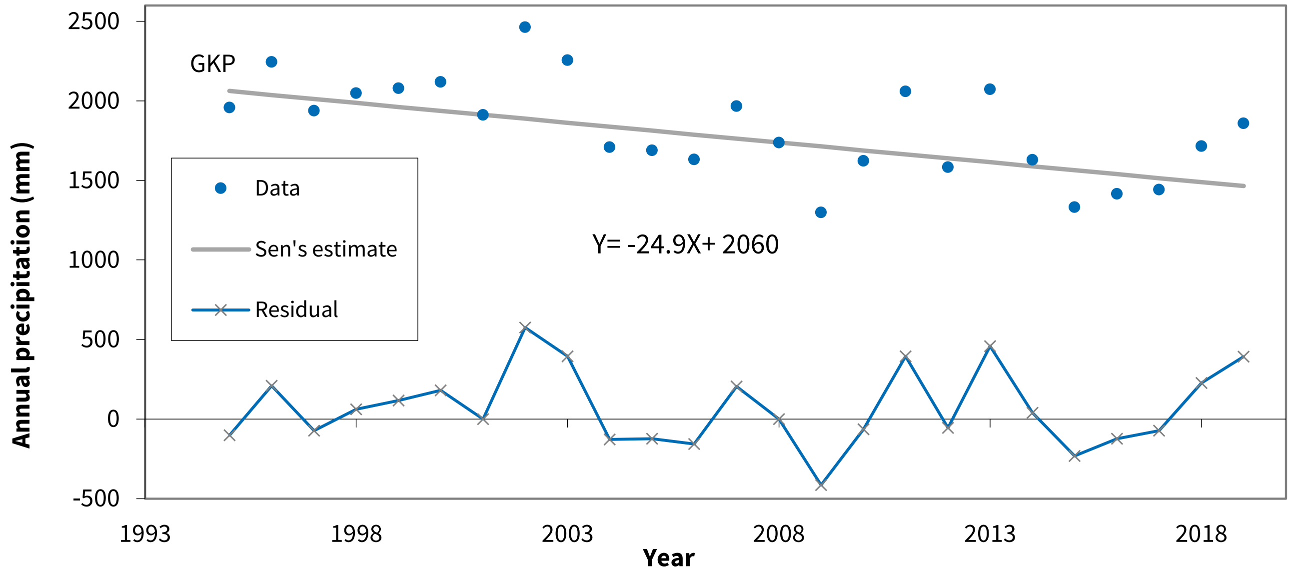


TABLE 2 IN-SITU PHYSICAL AND CHEMICAL PARAMETERS OF MONITORED SPRINGS IN 2018 AND 2019

Springs	2018				2019			
	EC (µS/cm)	TDS (mg/L)	Salinity (ppm)	Temperature (°C)	EC (µS/cm)	TDS (mg/L)	Salinity (ppm)	Temperature (°C)
Thulo Seem	154.1	109.8	74.8	14.8	148.6	104.4	74.7	14.5
Chisopani	170.7	121	82.3	15.2	163.5	115.5	82.2	15.0
Sungure Khola 1	183.0	128.7	88.3	15.2	173.0	122.4	87.6	15.0
Sungure Khola 2	169.1	120.1	82.2	14.4	158.5	112.1	80.1	14.4
Naudhara	202.3	148.9	101.7	16.1	197.9	140.7	100.8	15.7
Kuna Khola 1	185.0	131.5	89.3	13.6	172.5	123.6	86.6	13.4
Devithan	190.6	134.9	88.0	15.3	187.5	131.0	92.2	15.3
Khalte	231.5	164.4	110.7	16.4	216.6	159.6	114.0	16.3
Tripyani	181.2	131.9	91.5	16.1	176.1	131.9	88.8	14.8

Note: Data are available for only nine springs. Water quality was measured only for Kuna Khola 1 as Kuna Khola 2 lies in close proximity. Measurements for Godawari Kunda could not be undertaken as construction work was ongoing at the spring site

In order to determine the potability of the spring water, a detailed laboratory analysis was carried out at the Environment and Public Health Organization (ENPHO), Kathmandu in June 2018 and January 2019, that is, during the pre-monsoon and post-monsoon periods respectively. The spring water was analysed for 30 physical, chemical, and microbiological parameters, detailed earlier in Section 2. These were measured against parameters set by the Nepal Drinking Water Quality Standards (NDWQS, 2005). The results are presented in Table 3.

Table 3 shows that the measured physical and chemical parameters of the water in the springs are largely within the limits set by NDWQS in both seasons, barring the fluoride concentration which was found below the NDWQS limits, and the nitrate concentration of Sildada Mul, where high levels of nitrate (240.9 mg/L) were detected during the early monsoon, possibly due to the fertilizer use in agricultural land just above the spring. Bottle-fed babies are at high risk of developing methaemoglobinaemia, caused by the consumption of too much nitrate (Fewtrell, 2004). While consumption of water with high concentrations of fluoride can cause fluorosis, drinking water with low levels of fluoride provides protection against dental problems, especially in children (Featherstone, 1999).

Besides these issues, the microbiological analysis showed high levels of total coliform bacteria and *E. coli* bacteria during the early monsoon but not so much in winter (Figure 13). Total coliform levels in the spring water samples ranged from 116 CFU/100 ml to more than 8,000 CFU/100 ml. The results show a decrease in total coliform in most samples in January 2019, except that of Thulo Seem where the concentration is above the detection limit (>8,000 CFU/100 ml) in both the seasons, possibly due to environmental contamination. Thulo Seem, a wetland, has a large source area contributing to the contamination. *E. coli* was present in low values in most springs in June except Devithan in which it was above the detection limit. This indicates relatively high levels of pathogens and these values decreased in January to less than 32 CFU/100 ml. Sungure Khola, which is a fracture spring, was found free of *E. coli* in both seasons.

The observations imply that spring water quality was better in winter than during the monsoon. This may be due to the fact that rainwater mixes with pollutants such as chemical fertilizers, animal and human droppings, and pesticides during the monsoon. The results show that the concentrations of all analysed dissolved ions (physical and chemical parameters) are within the limits set by the Government of Nepal's NDWQS. The sole exception was Sildada Mul, where high levels of nitrates were detected in June 2018.

3.3 Step 3: Understanding the social and governance systems related to springs

A comprehensive understanding of water use, its distribution patterns, and institutional and governance systems that are in place to manage springs is essential for planning effective mechanisms for spring revival, and also for measuring the socioeconomic impacts of spring revival activities (Step 6 of the protocol; Figure 3).

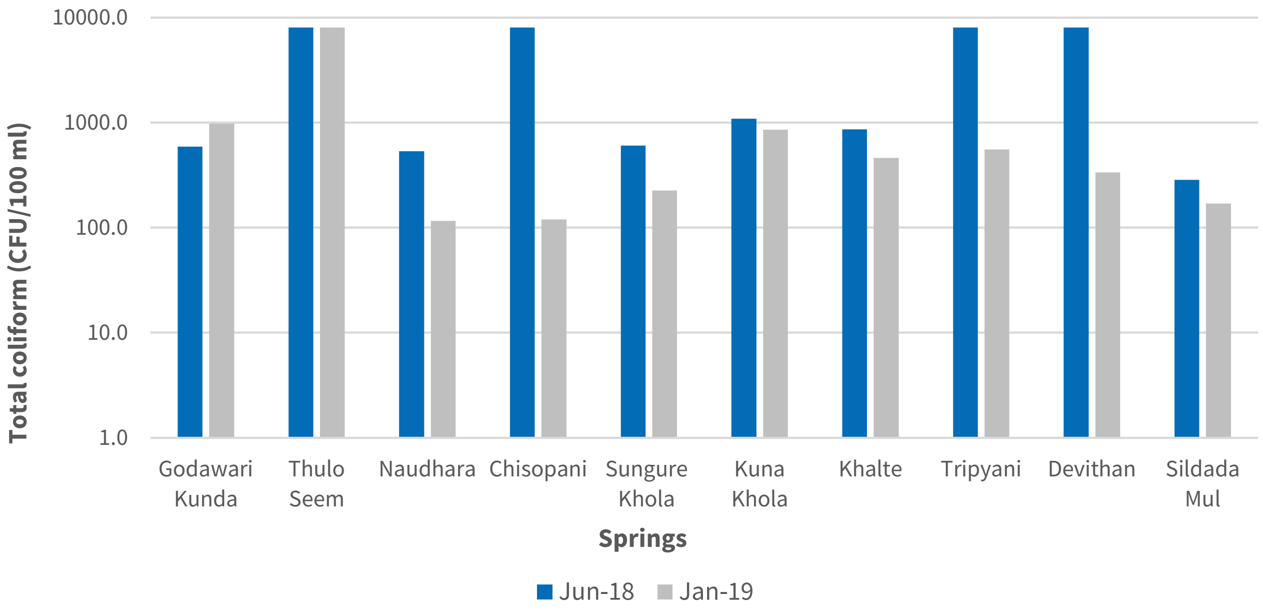
Communities in the Kathmandu Valley use multiple sources of water to satisfy their needs. These include

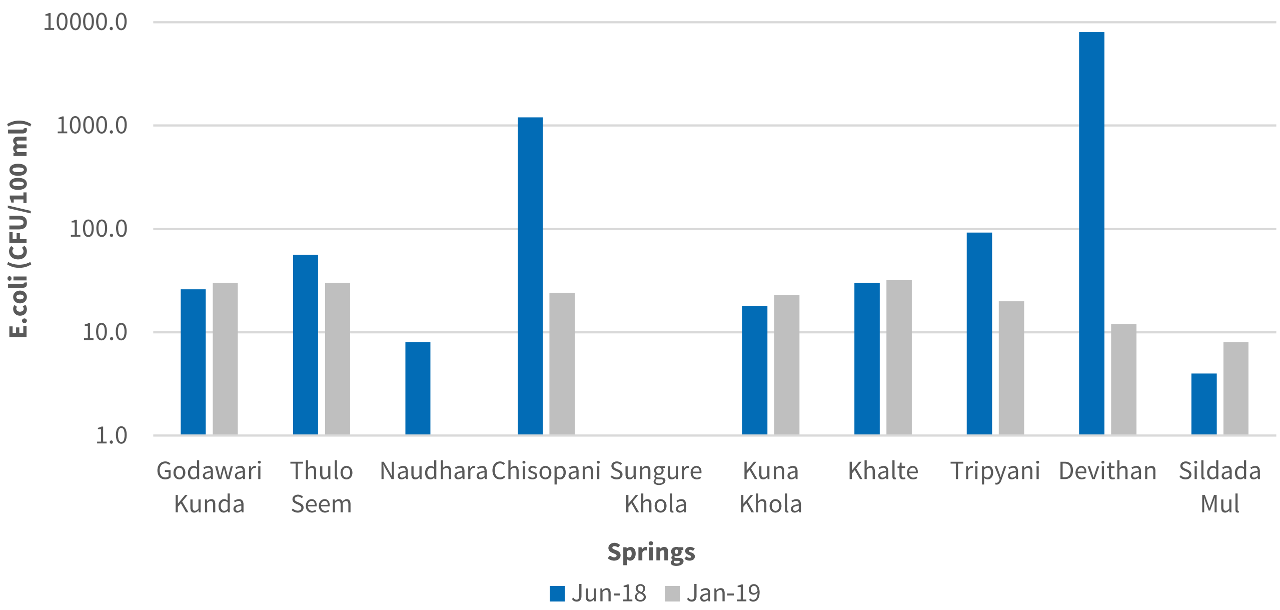
TABLE 3 PRE- AND POST-MONSOON VARIATIONS IN WATER QUALITY IN SPRING WATER SAMPLES, MEASURED AGAINST NDWQS STANDARDS

Parameter	Unit	NDWQS limit	June 2018		January 2019	
			Minimum	Maximum	Minimum	Maximum
pH	–	6.5-8.5	6.6	8	7.2	8.1
EC	µS/cm	1,500	104	267	107	242
TDS	mg/L	1,000	95.8	191	72	133
DO	mg/L	–	5.2	7.9	7	9
Turbidity	NTU	5(10)	<1	2.1	<1	2.3
Total hardness	mg/L	500	59.0	143.0	56.7	144.9
Calcium	mg/L	200	20.0	45.7	21.6	44.9
Magnesium	mg/L	–	1	5.6	<1	7.7
Sodium	mg/L	–	0.7	4.2	<1	4.1
Potassium	mg/L	–	0.4	1.3	<1	1.6
Carbonate	mg/L	–	<2	<2	<2	<2
Bicarbonate	mg/L	–	<2	33	60	134
Sulphate	mg/L	250	<1	3.9	3.3	8.2
Chloride	mg/L	250	1	2	<1	34.5
Nitrate	mg/L	50	<0.2	240.9	<0.2	5.4
Fluoride	mg/L	0.5 –1.5	<0.5	1.36	<0.5	<0.5
Ammonia	mg/L	1.5	<0.05	0.26	<0.05	0.19
Cyanide	mg/L	0.07	<0.05	<0.05	<0.05	<0.05
Aluminium	mg/L	0.2	<0.05	<0.05	<0.05	<0.05
Arsenic	mg/L	0.05	<0.005	<0.005	<0.005	<0.005
Cadmium	mg/L	0.003	<0.003	<0.003	<0.003	<0.003
Chromium	mg/L	0.05	<0.02	<0.02	<0.02	<0.02
Copper	mg/L	1	<0.02	<0.02	<0.02	<0.02
Lead	mg/L	0.01	<0.01	<0.01	<0.01	<0.01
Manganese	mg/L	0.2	<0.05	<0.05	<0.05	<0.05
Zinc	mg/L	3	<0.05	<0.05	<0.05	<0.05
Mercury	mg/L	0.001	<0.001	<0.001	<0.005	<0.001
Iron	mg/L	0.3(3)	<0.05	0.27	<0.05	0.28
E. Coli	CFU/100 mL	0	0	>8,000	0	32
Total coliform	**CFU/100 mL**	**0**	**284**	**>8,000**	**116**	**>8,000**

Note: Values above and below safe levels have been marked in red

FIGURE 13 TOTAL COLIFORM AND *E. COLI* CONCENTRATIONS IN SPRINGS DURING JUNE 2018 AND JANUARY 2019





traditional stone taps, wells, treated jar water, tanker delivery, and piped water networks. For most communities in the region, stone water taps have been the primary source of drinking water since time immemorial. This ancient water source has persisted through Kathmandu's rapid urbanization and continues to be an important source of household water, especially for the city's lowest-income residents (Molden et al., 2016). Kathmandu's stone spouts have remained important not only because they provide water to communities, but also because they serve to anchor the city's current rapid urbanization to its past cultural heritage (Molden and Meehan, 2018).

However, in recent years, the increased pumping of groundwater has depleted the shallow aquifers that supply the stone taps, even as the increasing population density has intensified the risk of groundwater contamination across the valley (Shrestha et al., 2016) GIS based DRASTIC model have been used to assess intrinsic aquifer vulnerability to pollution whereas Groundwater Risk Assessment Model (GRAM. Thus, the stone spouts are over time becoming less reliable, both in terms of the quantity and quality of water they supply.

Most households in Kathmandu are serviced by piped water networks. For many households in Kathmandu, jar water is also the go-to source of water for both drinking and cooking. Another major source is water delivered to individual households or community tanks filled by water tankers. The tankers are filled at specific water collection points, usually rivers or ponds in the hills outside of city, such as Godavari. These are generally operated by small, private businesses.

3.3.1 Water distribution

Springs originating in the Godavari watershed are tapped and controlled by WUGs, whereas in the Chapakharka watershed, people also fetch water directly from the springs. A social survey was conducted with the WUGs to understand the water distribution system, including pipelines and water tankers. Nineteen WUGs and five small, local water supply systems were identified that source all or a part of their water from the Godavari and Chapakharka springs (see Annex 2). WUGs in the region fall into three categories by size – large, medium, and very small (Table 4). They serve more than a thousand households (large), 50–300 (medium), or less than 50 (very small) households respectively. There are no WUGs of an intermediate size (300–700 households).

TABLE 4 WATER USER GROUPS BY SIZE

Category	Number of households served	Number of WUGs	Households served
Large	Greater than 1,000	7	9,183
Intermediate	300–700	0	0
Medium	50–300	10	1,402
Small	Less than 50	7	120

Key informant interviews were conducted with chairpersons and vice-chairpersons of the 24 WUGs. Of the 19 WUGs, 14 WUGs tap water from springs in the Godavari watershed, two WUGs source water from the Godavari Khola, and three from springs in the Chapakharka watershed. A conceptual water distribution map of the region is shown in Figure 14. The Godavari springs in the diagram represent the springs of the Godavari and Chapakharka watersheds that serve multiple users.

Six water tanker filling stations were identified that pump water either directly from the Godavari Khola or tap the groundwater immediately adjacent to it. These six stations supply 2,000–4,000 cubic metres (m^3) of water per day, depending on the season, to downstream users such as households, hospitals, and apartments in Kathmandu and Lalitpur. During the dry season (October–May), tankers supply up to 4,000 m^3 per day. Rapid sand filtration and chlorination is commonly carried out in these filling stations, with a few conducting weekly tests for hydrogen sulphide (H_2S). The rapid sand filter is to reduce turbidity only. The chlorine renders inactive the harmful micro-organisms present in the water, but not all kind of micro-organisms. Which is why it is not supplied for drinking, and only for other household uses.

In order to better understand how and where the water from the region is used, a coverage map of water distribution networks in the area was created through a combination of manually-taken GPS points, KIIs, and engineering maps of the various water systems (Figure 15).

3.3.2 Water supply scheduling

All the WUGs reported needing to schedule water supply to users during the dry season, when water flow is low. Most WUGs also reported scheduling water supply during the monsoon. Most water delivery systems supply water to all their users on an equal basis, either once or twice per day (Table 5). Two of the larger WUGs, Harisiddhi and Chapakharka, employ a more complex scheduling system, distributing water to different parts/blocks of their network at different times of day. The WUGs using more complex scheduling systems reported prioritizing those parts of their networks with more dense populations.

Our results indicate that large water system operators and their customers consider water supply once or twice a day as acceptable. Though the WUGs did not specifically elaborate what kind of additional service they would like in the future, small and medium WUGs indicated that for them the ideal situation would be a continuous water supply, even though that doesn't seem possible in the near future.

TABLE 5 WATER SCHEDULING BY SEASON AND SIZE OF THE WUG

Wet season scheduling	Number of large WUGs	Number of medium WUGs	Number of small WUGs
Intermittent supply, no schedule	0	0	0
Weekly	1	2	0
Once daily	1	1	0
Twice daily	5	3	2
Continuously	0	4	5

Dry season scheduling	Number of large WUGs	Number of medium WUGs	Number of small WUGs
Intermittent supply, no schedule	0	2	0
Weekly	1	0	0
Once daily	2	2	0
Twice daily	4	5	2
Continuously	0	1	5

FIGURE 14 CONCEPTUAL WATER DISTRIBUTION MAP OF GODAVARI AREA

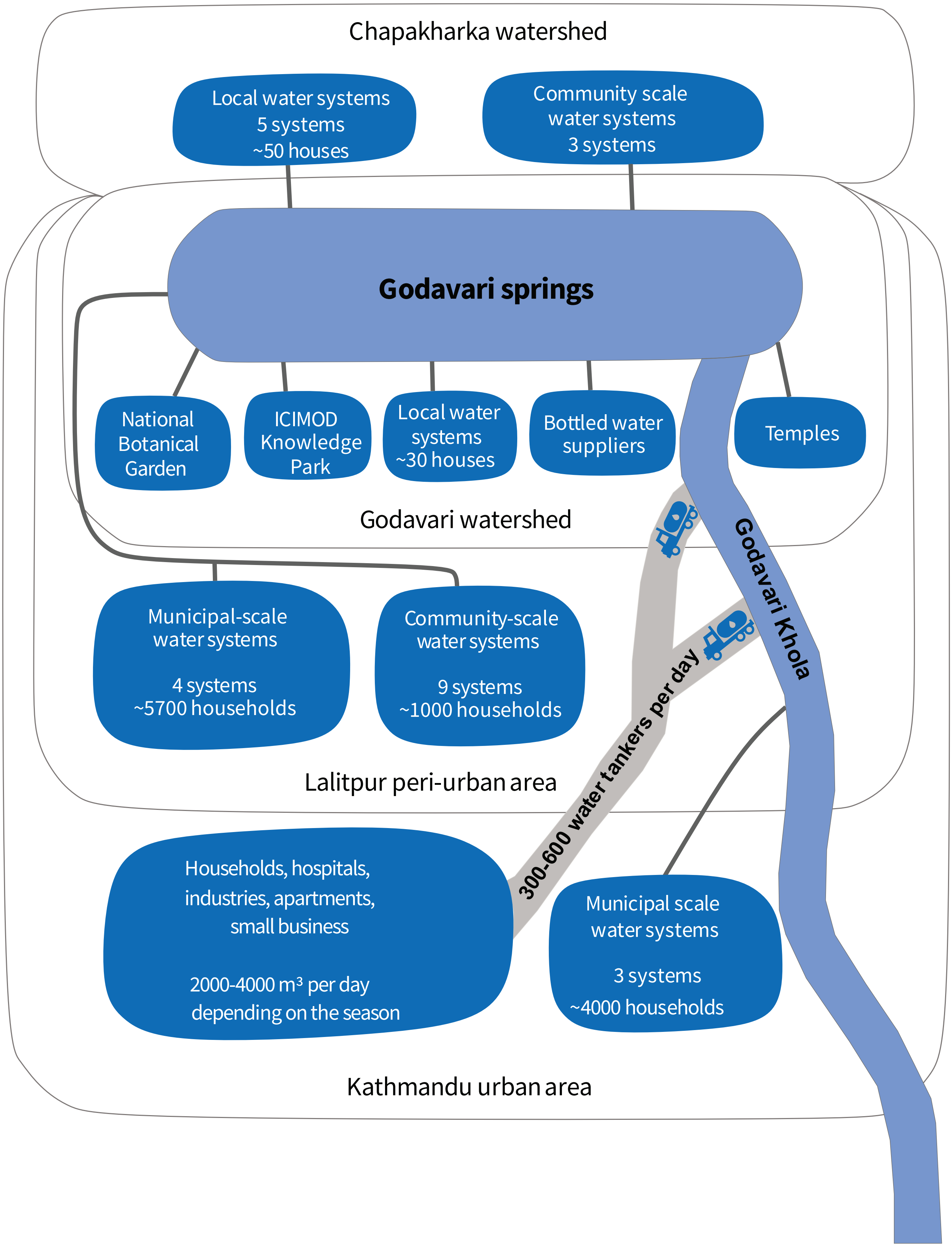
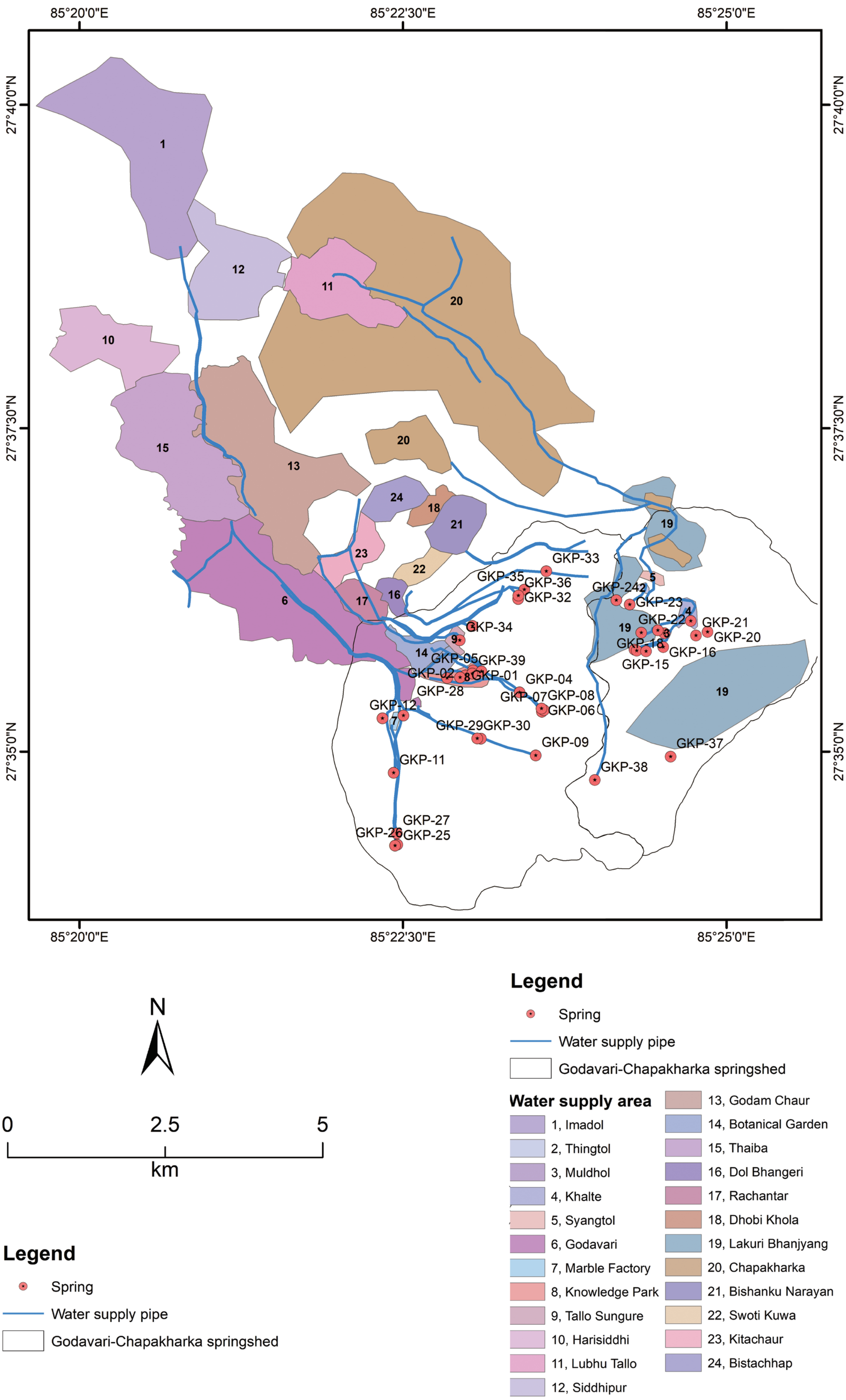


FIGURE 15 WATER DISTRIBUTION NETWORKS IN THE GODAVARI AREA



3.3.3 Water treatment

The extent to which water is treated in any of these systems is entirely dependent on the infrastructure installed with the initial project. Most water systems here that get their supply from rivers or large streams have some sort of filtration or method to trap sediment. Water systems with springs as their source, which comprise the majority of systems in the area, might mix bleaching powder into a storage tank, but in general did not report treating their water (Table 6). Manually adding bleaching powder to a reserve tank may be effective, though its effectiveness depends on how the storage tank is managed. More effective chlorination may be achieved by a continuous injection of it into the main distribution pipe that is connected to the storage tank. Most WUGs reported that they use bleaching powder in small amounts and irregularly, though two of the large WUGs reported a more controlled means of chlorination.

A continuous monitoring of water quality, in addition to regular treatment, is necessary to ensure that the treatment has been effective. WHO drinking water quality standards suggest testing for both total coliform levels and *E. coli* as a general indicator of water quality. These tests require special equipment and reagents, and as such must be performed in a laboratory. While a number of these laboratories exist in Kathmandu, the organizers of rural water systems in the Godavari region have limited access to them because of the distance and the price of the tests.

A test that is commonly carried out in the region though is the hydrogen sulfide (H_2S) test. It detects a by-product of certain gut bacteria, which can indicate whether a water source has been faecally contaminated. H_2S testing is widely known and used in the Godavari region as it is both cheap and portable. It is also, unfortunately, not very sensitive to low levels of contamination and does not give a quantitative indication of water quality.

Small WUGs generally do not treat their water, while medium and large systems were more likely to have some form of water treatment.

TABLE 6 **WATER TREATMENT METHODOLOGIES BY WUG SIZE**

Treatment	Number of large WUGs	Number of medium WUGs	Number of small WUGs
Combined treatment (filtration and bleaching)	6	4	0
Filtration and/or sedimentation	3	2	0
Bleaching (done manually)	3	4	0
Bleaching (controlled)	2	0	0

Microbiological testing	Number of large WUGs	Number of medium WUGs	Number of small WUGs
No water testing	2	8	7
Irregular water testing (H_2S)	3	2	0
Regular water testing (coliform)	2	0	0

3.3.4 Sources of finance

The largest WUGs all reported that their initial funding came from a governmental body, while the medium-sized WUGs are primarily funded by non-governmental organizations (NGOs) or international non-governmental organizations (INGOs). The small WUGs are either self-funded or funded by an NGO.

Cost recovery is important for both the medium- and long-term financial sustainability of water systems. Three kinds of water tariffs were reported by WUGs in the region – no fee, a flat monthly fee, and tiered water pricing. The first two schemes are self-explanatory. Tiered water pricing raises the tariff with a rise in water consumption both at households and commercial establishments. Tiered pricing is intended to be progressive, as those who use the most water from these systems are presumed to be the most well off, and thus have to pay the most for their water. Tiered pricing is also intended to promote water conservation. It should be noted that in order to implement tiered pricing, a water system must be equipped with water meters in every household, which may represent a significant capital investment for a small water system.

As might be expected, most of the small water systems either charge a simple, flat monthly rate or nothing at all. The smallest WUGs (ranging between 2–33 households) did not report charging a monthly tariff (Table 7). Among the larger water systems, a tiered pricing scheme has been implemented, except for in Harisiddhi, which does not charge its water users after the initial connection fee has been paid.

TABLE 7 **TARIFF STRUCTURE BY WUG SIZE**

Tariff structure	Number of large WUGs	Number of medium WUG	Number of small WUGs
No charge	1	0	7
Flat monthly fee	2	6	0
Tiered pricing	4	4	0

3.4 Step 4: Hydrogeological mapping, development of conceptual layout, and identification of recharge areas

The delineation of the recharge area of springs is one of the important aspects of springshed management. Hydrogeological mapping, which involves a detailed study of rocks, rock structures, streams and springs, aids in delineating a springshed and identifying recharge areas. Three steps are part of this phase: hydrogeological field mapping, creating a conceptual hydrogeological layout of the springshed, and identifying the recharge area of a spring. A conceptual hydrogeological layout depicts the relation of a spring to the local geology. It helps in identifying the aquifer and type of spring and in the demarcation of the recharge zone for springshed management and revival.

We carried out detailed geological studies of the 11 studied springs for delineation of their recharge area. A conceptual layout for each spring was developed based on hydrogeological mapping. The typology of each spring was identified; the recharge zone for each of the springsheds was identified; and a set of measures within the recharge area suggested (Figures 16–42). The satellite images have been sourced from Google Earth.

3.4.1 Thulo Seem

Thulo Seem, located inside the Godavari Knowledge Park, is supported by a huge wetland, thus keeping the spring perennial. The term 'Thulo' in Nepali itself indicates a spring that bears high discharge.

The main hydrogeological unit that supports this spring is loose colluvial deposits found all across the base of the Godavari hills (Figure 17). It is difficult to gauge their extent (thickness) due to the presence of thick forests all across the Godavari region.

In the case of Thulo Seem, these loose colluvial deposits are found overlying southwest-dipping limestone of the Chandragiri Formation. The spring emerges in the form of multiple seepages, clearly indicating that it is a depression spring.

FIGURE 16 GOOGLE EARTH IMAGE OF THULO SEEM WITH GEOLOGICAL OVERLAY

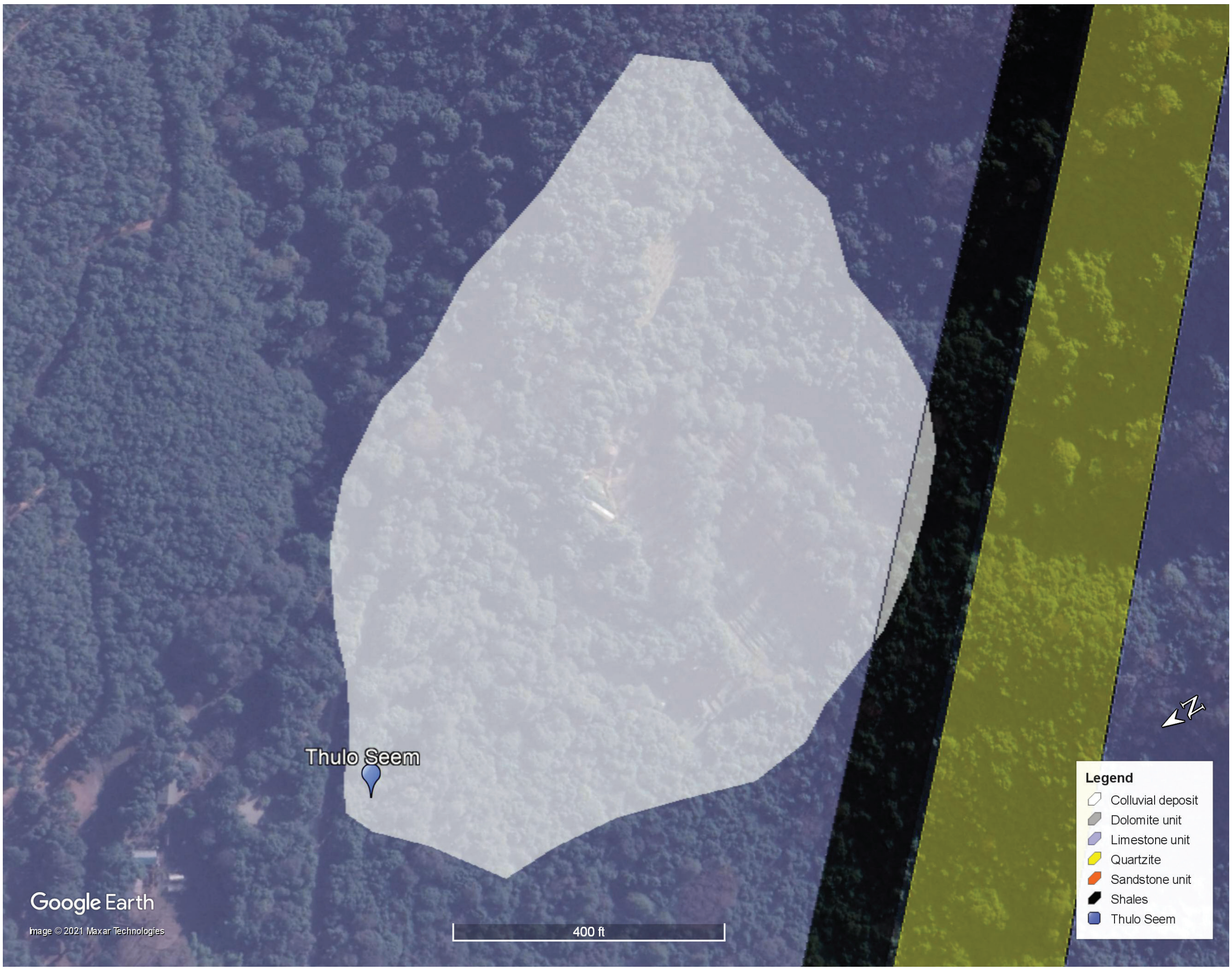
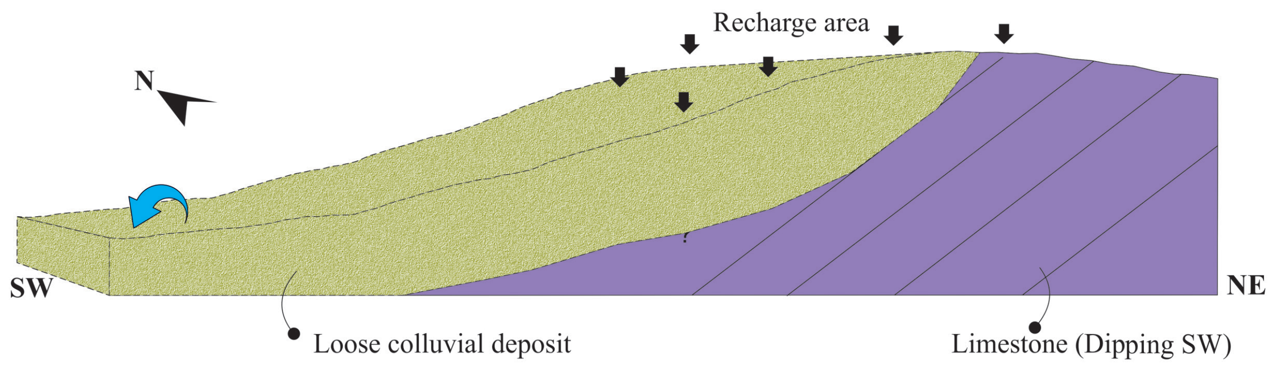


FIGURE 17 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF THULO SEEM WITH THE RECHARGE AREA DEMARCATED



The spring's recharge area lies exactly above the spring (Figure 18) up to the point where loose colluvial deposits are to be found. There are weathered sections at some locations but we could not find any uniformity in this and hence they are considered to be the part of the loose colluvial deposits that forms the aquifer feeding Thulo Seem.

3.4.2 Chisopani

Chisopani spring is situated in the Godavari Knowledge Park campus near Sungure Khola. This spring is one of the primary sources of water for multiple activities carried out in the park, including its training venue. The exact source of the spring is not visible as there is a collection tank built around it. Local people say that the spring emerges at multiple points, making it a classical example of a depression spring (Figure 19).

FIGURE 18 THE RECHARGE AREA FOR THULO SEEM

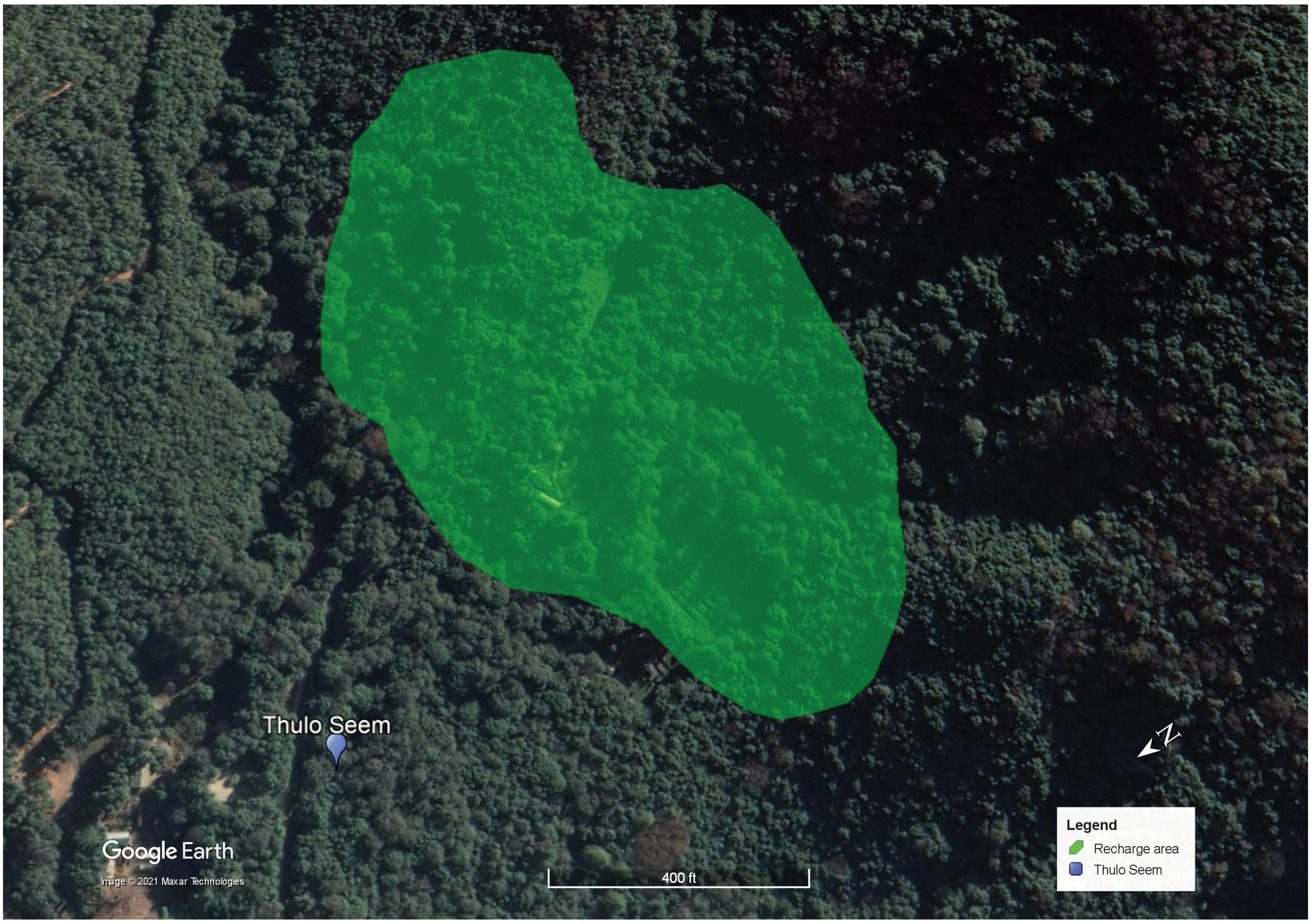
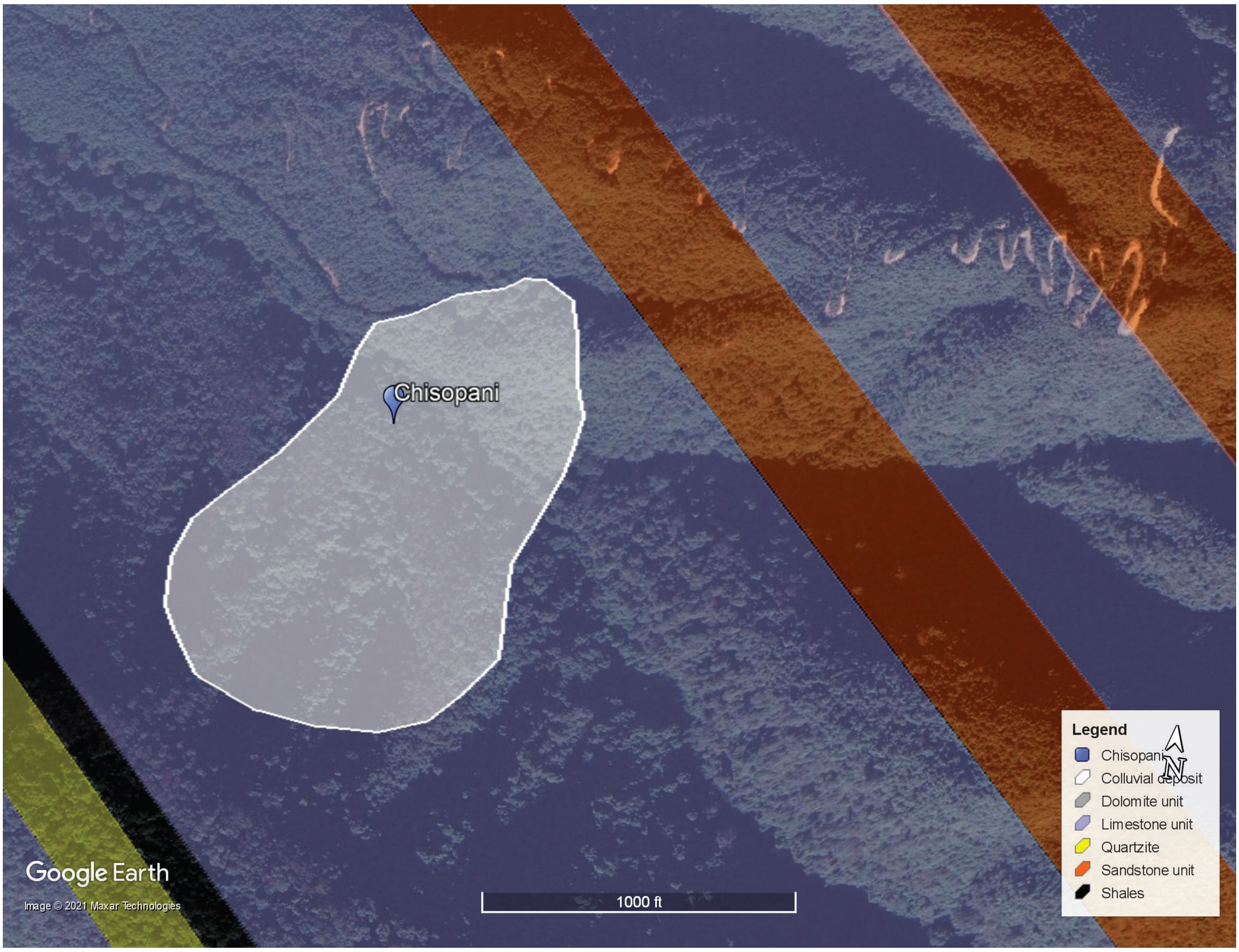


FIGURE 19 GOOGLE EARTH IMAGE OF CHISOPANI WITH GEOLOGICAL OVERLAY



The spring emerges at a slope facing the northeast towards Sungure Khola. There is no outcrop exposed in its vicinity, barring the colluvial deposit along the slope. It was difficult to gauge the thickness of the colluvial deposit as there was no clean boundary exposed between the underlying rocks and the deposit. Considering the observed geological setting, it is certain that the primary storage that supports Chisopani spring occurs in colluvial deposit. However, the spring is perennial in nature, which indicates some possible contribution from the underlying limestone as well (Figure 20) through karstic features present in them.

The recharge area for Chisopani (Figure 21) was identified on the basis of the estimated extent of the colluvial deposit that forms the primary aquifer. If the identified recharge area happens to exceed the actual exposed deposit, it will help in recharging the underlying karstic limestone, which probably enables Chisopani to be a perennial spring.

3.4.3 Sungure Khola 1 and 2

Sungure Khola is a classic example of a fracture spring; it emerges at two locations very close to each other. The underlying geology comprises a folded sequence of sandstone and limestone (Figure 22). The fold axis trends in a NE–SW direction. The limestones are interbedded with marl and also show karstic features in some locations.

The spring, however, is fed by a fracture network that occurs in both the limestone and sandstone. The maximum groundwater storage supporting Sungure Khola most likely occurs in the fractured and karstic limestone. Sandstone is quite hard and compact in nature, with low intrinsic porosity.

The dominant fracture network through which the spring emerges trends in a NE–SW direction and dips towards the southeast (Figure 23). There is another fracture network dipping northwest but it holds little significance in the case of Sungure Khola.

FIGURE 20 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF CHISOPANI WITH THE RECHARGE AREA DEMARCATED

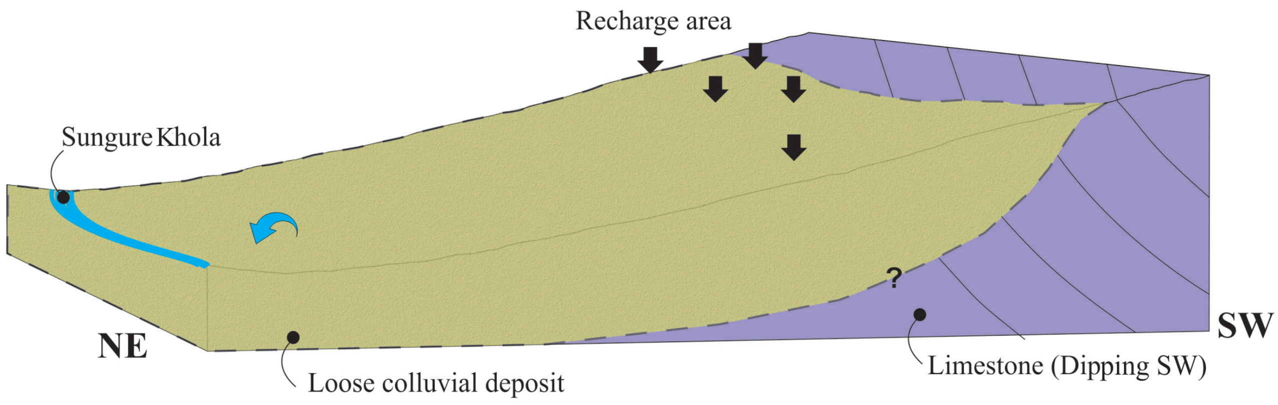


FIGURE 21 THE RECHARGE AREA FOR CHISOPANI

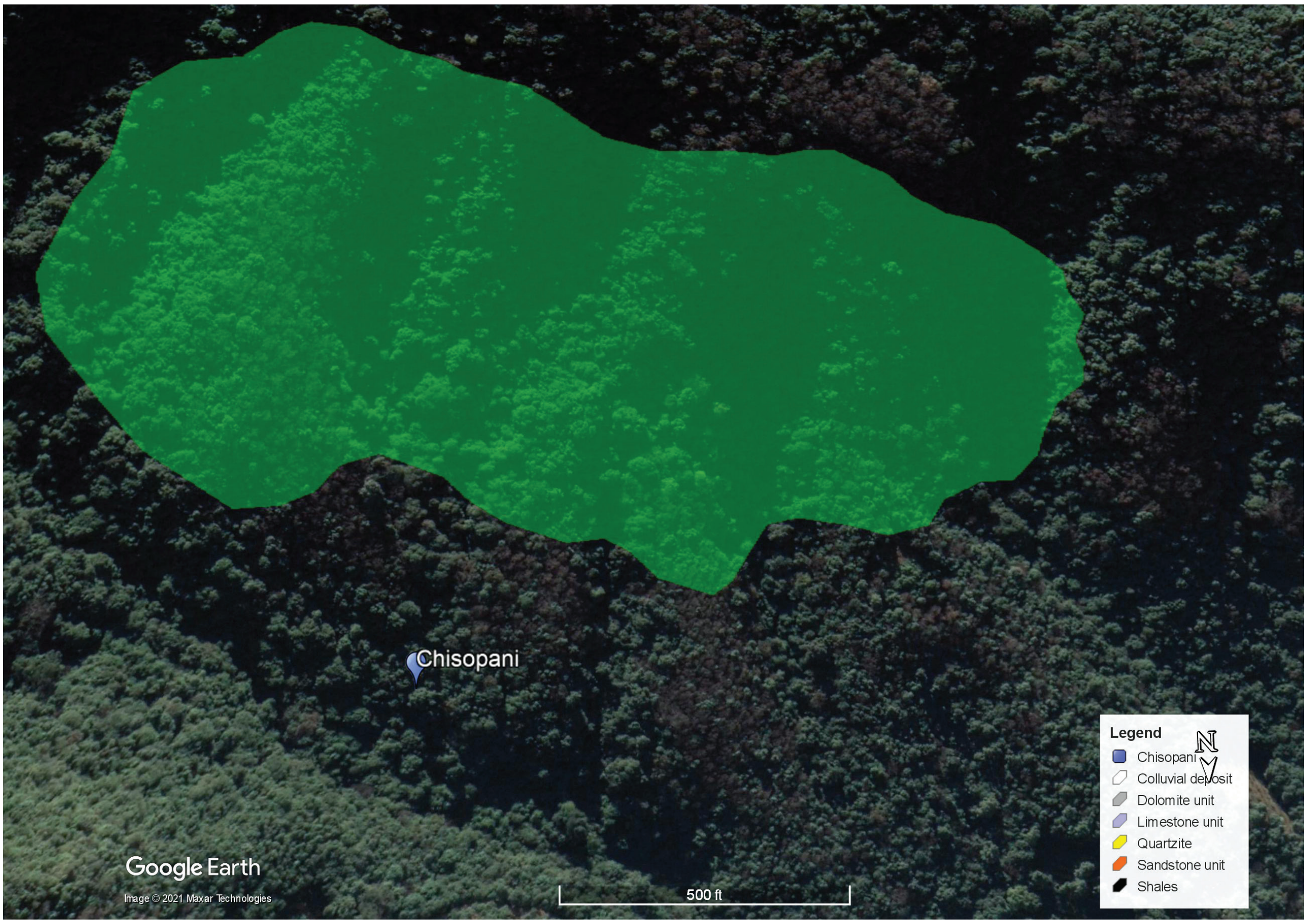


FIGURE 22 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF SUNGURE KHOLA SPRING WITH THE RECHARGE AREA DEMARCATED

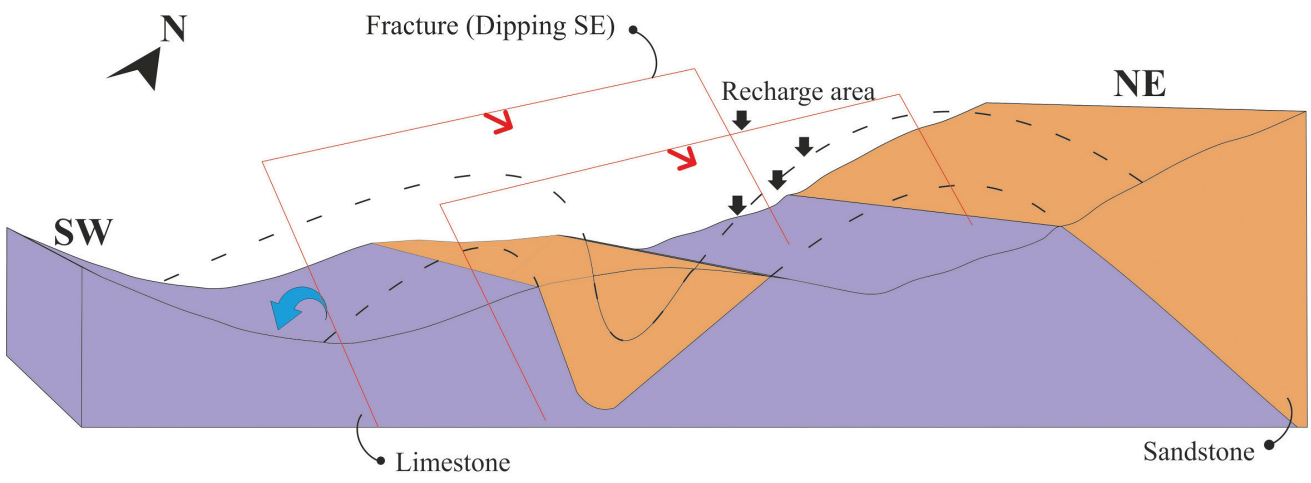
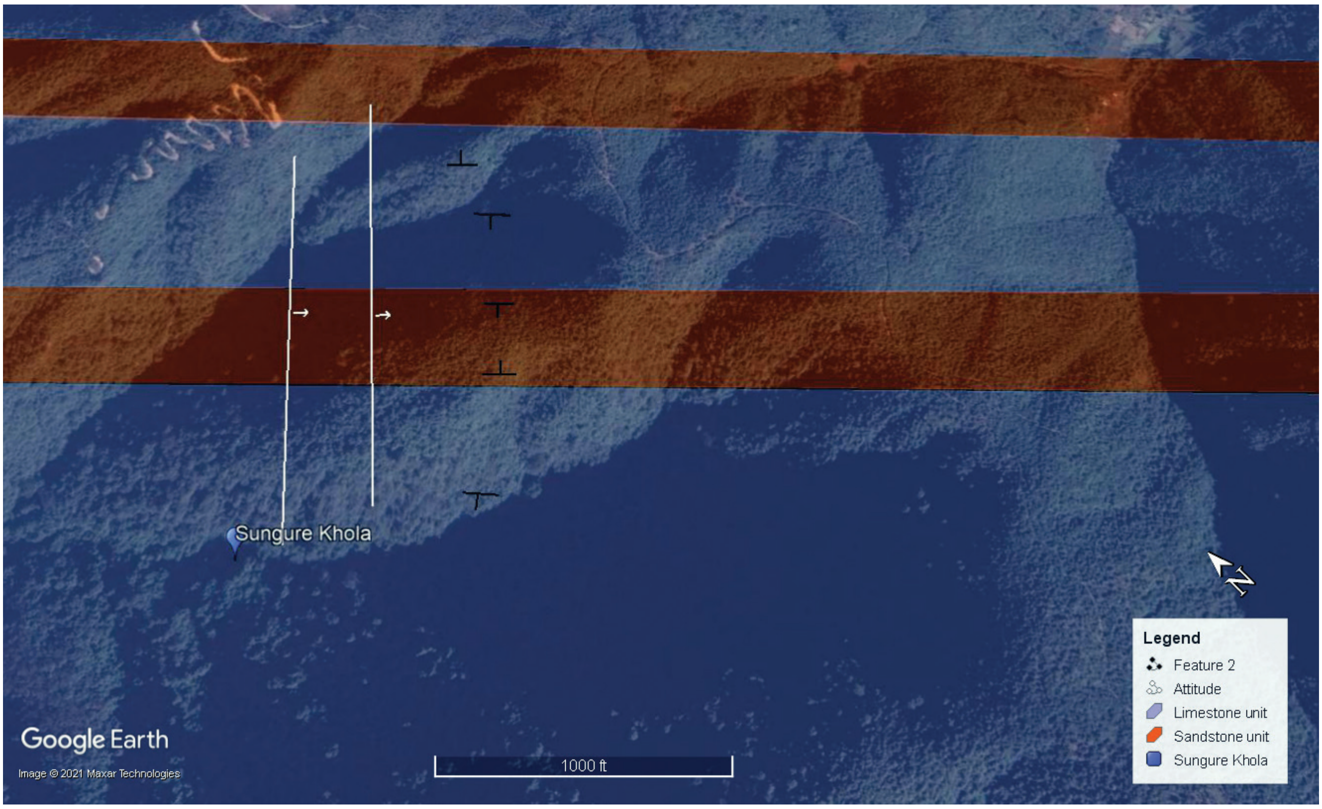


FIGURE 23 GOOGLE EARTH IMAGE OF SUNGURE KHOLA WITH GEOLOGICAL OVERLAY



The spring's recharge area (Figure 24) was identified on the basis of fractures and bedding planes measured in the lithostratigraphic units. Considering the southwesterly dipping beds and fracture trending in the NE-SW direction and dipping SE, the recharge area falls in a N–NE direction on both sides of the ridge.

3.4.4 Naudhara

Naudhara is another high-discharge spring in the Godavari springshed. It emerges on the slope facing northwest. Its exact source is not clear as the path to reach it is not accessible.

The dominant geology here comprises limestone dipping in the southwesterly (Figure 25) direction and striking NW–SE (Figure 26). However, weathered

FIGURE 24 THE RECHARGE AREA FOR SUNGURE KHOLA

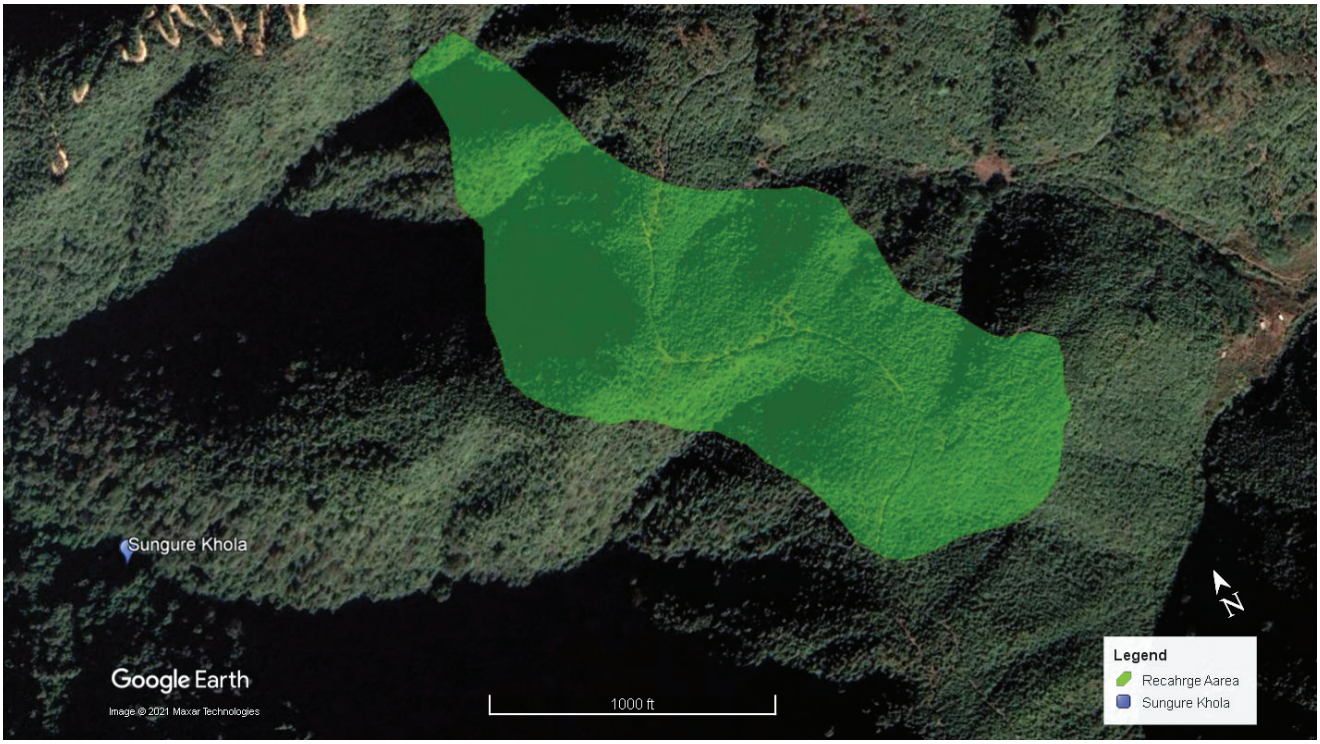
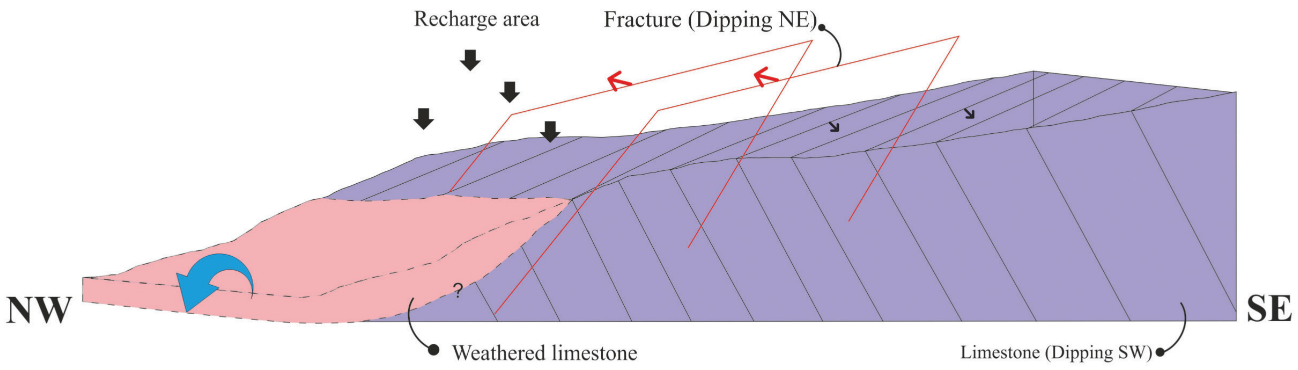


FIGURE 25 GOOGLE EARTH IMAGE OF NAUDHARA WITH GEOLOGICAL OVERLAY

FIGURE 26 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF NAUDHARA SPRING WITH THE RECHARGE AREA DEMARCATED



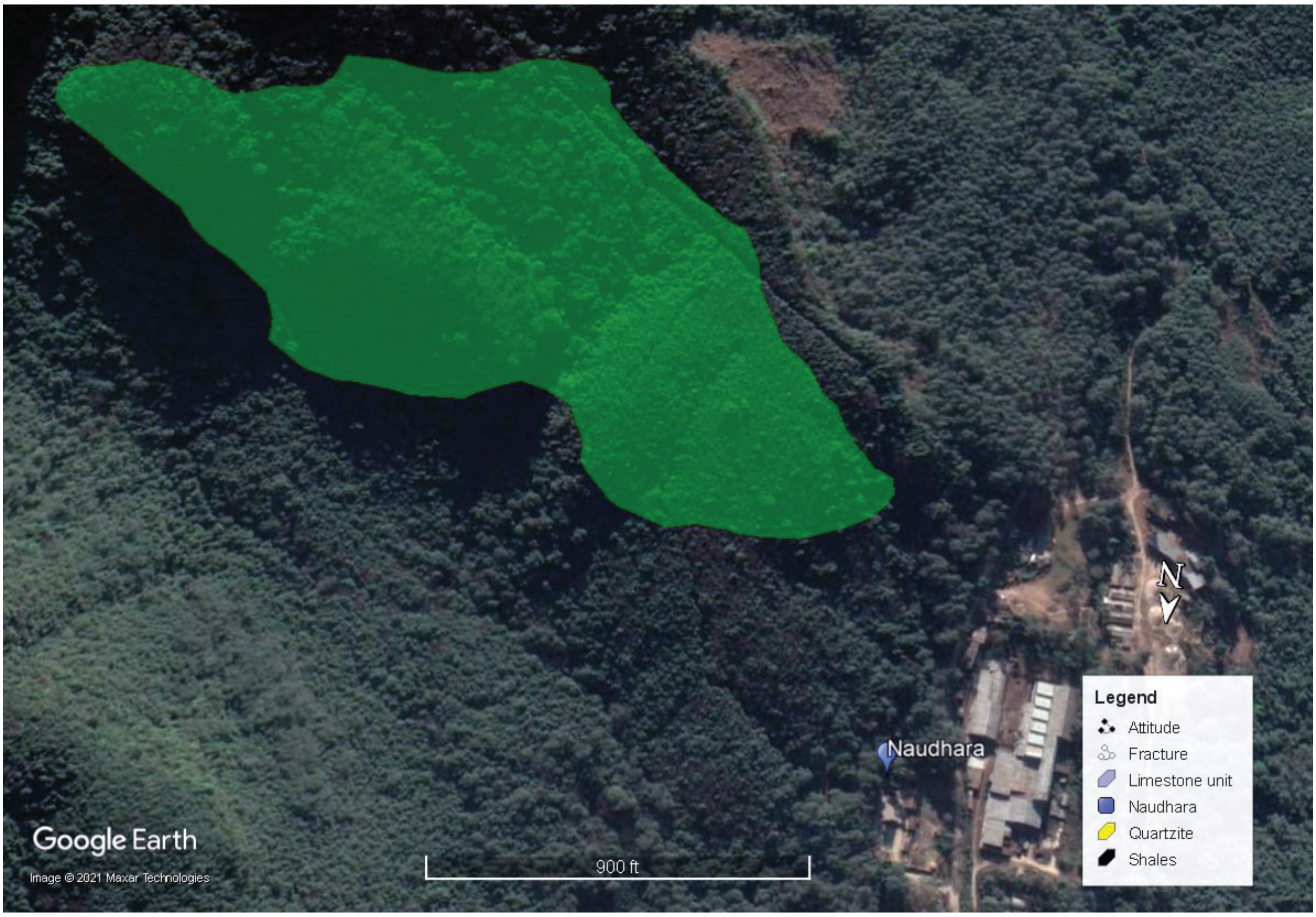
sections are exposed in the vicinity of the spring, indicating that the spring discharges out through it, forming a depression spring. It seems unlikely that the storage in the weathered section alone can support such high discharge. Thus, it is evident that the underlying fractured-karstic limestone provides the additional storage to support the high spring discharge.

The recharge area of the Naudhara spring (Figure 27) was thus identified by considering the fact that both the underlying fractured-karstic limestone and the weathered limestone together form an aquifer that supports its high discharge. In fact, the extent of recharge area currently identified might be an underestimation to a certain extent because the limestone, being karstic in nature, may well be receiving recharge from multiple micro-locations.

3.4.5 Hiuende

Hiuende is located at the base of a hill with the slope facing northeast. The spring emerges out of colluvial/fluvial deposit, primarily forming a depression

FIGURE 27 THE RECHARGE AREA FOR NAUDHARA



spring. However, the spring is also supported by the underlying, fractured limestone unit, which is also seen at the spring's source. The primary fracture sets trend NW–SE, dipping to the northeasterly direction, hence creating an opening along the apparent dip of the limestones. Hence, Hiuende is a combination of a fracture type and depression type of spring.

The colluvial/fluvial deposit mostly allows for only a limited storage, which will be reflected in peak discharge occurring during the monsoon season, while the storage in the fractured limestone ensures the spring's perenniality. Examining the regional geology, it appears that the Hiuende spring emerges in the syncline of a large fold (Figure 28).

The spring's recharge area (Figures 29 and 30) was identified on the basis of fractures and dips in the limestone which provides the spring its primary storage. The limited storage in the colluvial deposits will anyway only enable seasonal flows (in the monsoon) under natural conditions. Thus, the main focus behind identifying the recharge area is to increase saturation in the fractured limestone.

3.4.6 Devithan

Devithan is located in the Chapakharka region on the other side of the Godavari springshed. This spring is interesting; it had four primary source points, one of which seized up after the earthquake of 2015. Despite that, its overall discharge is quite high, at least during the monsoon.

The geological set-up around it mainly comprises sandstone of the Chapakharka unit (Figure 31), dipping in a southwesterly direction with multiple fractures traversing the entire unit. The spring emerges out of loose colluvial deposit. Although the deposit provides limited storage, in this case too the underlying sandstone provides additional storage to sustain its perennial nature. Thus, Devithan forms as a combination of a fracture and depression spring.

FIGURE 28 GOOGLE EARTH IMAGE OF HIUENDE SPRING WITH GEOLOGICAL OVERLAY

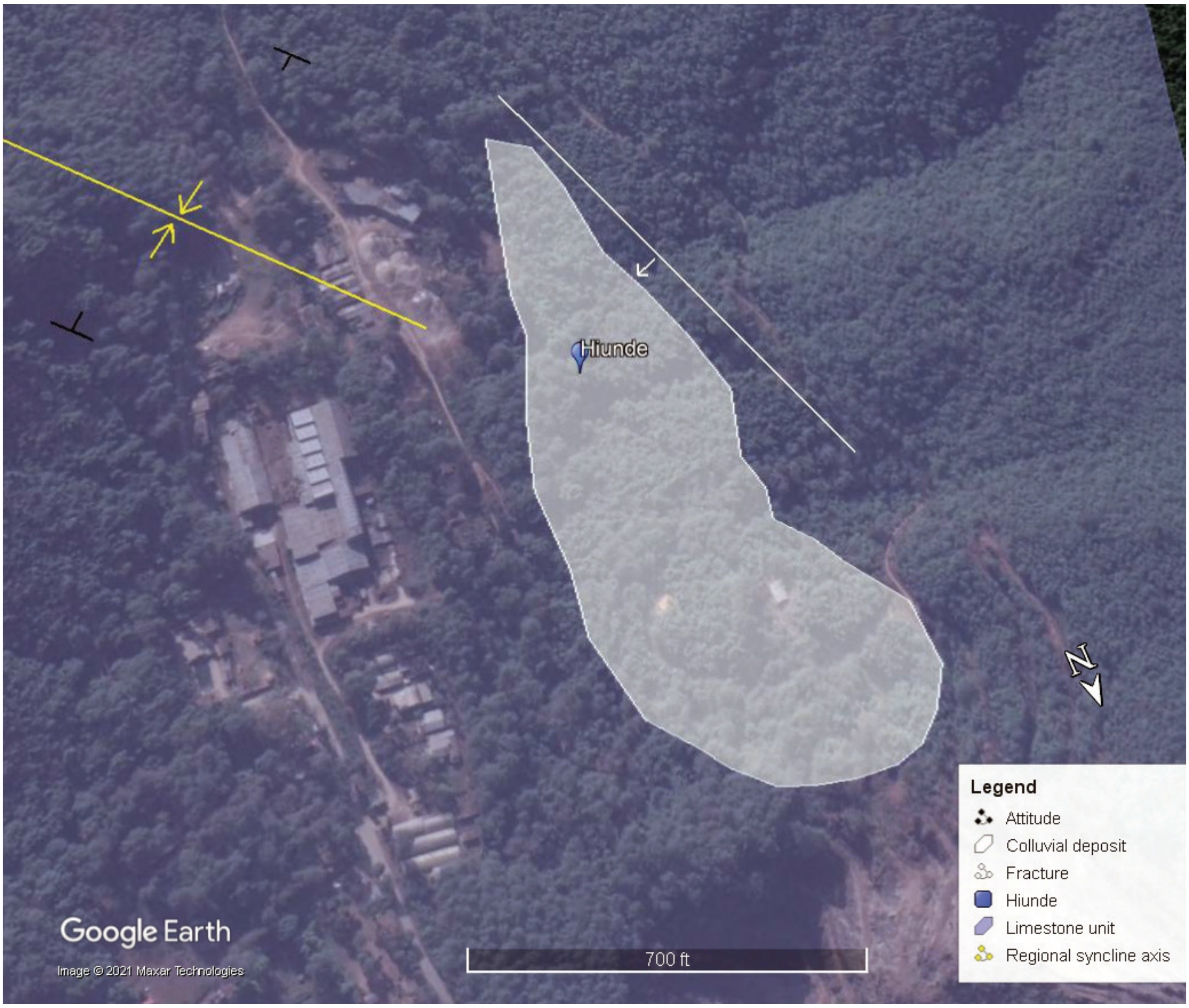


FIGURE 29 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF HIUENDE SPRING WITH THE RECHARGE AREA DEMARCATED

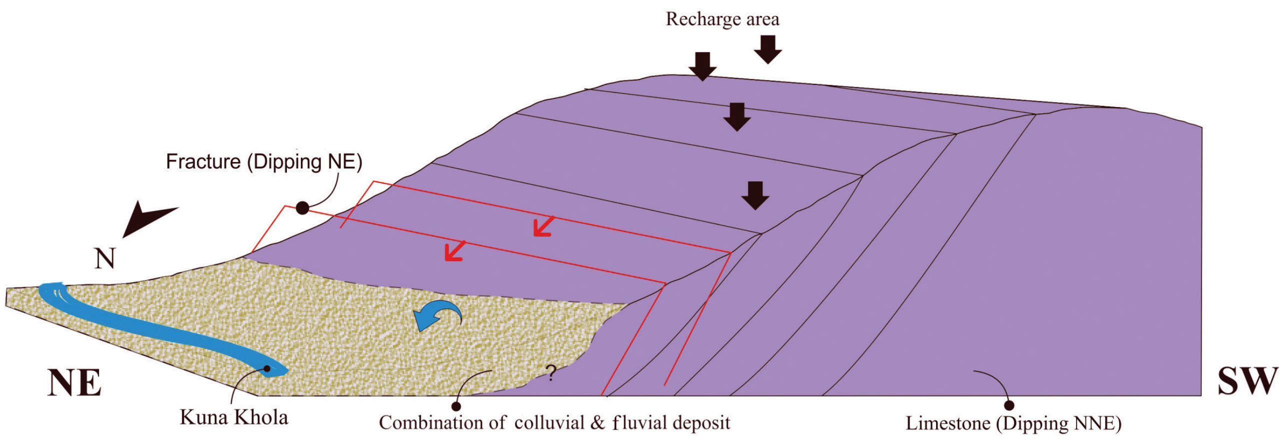
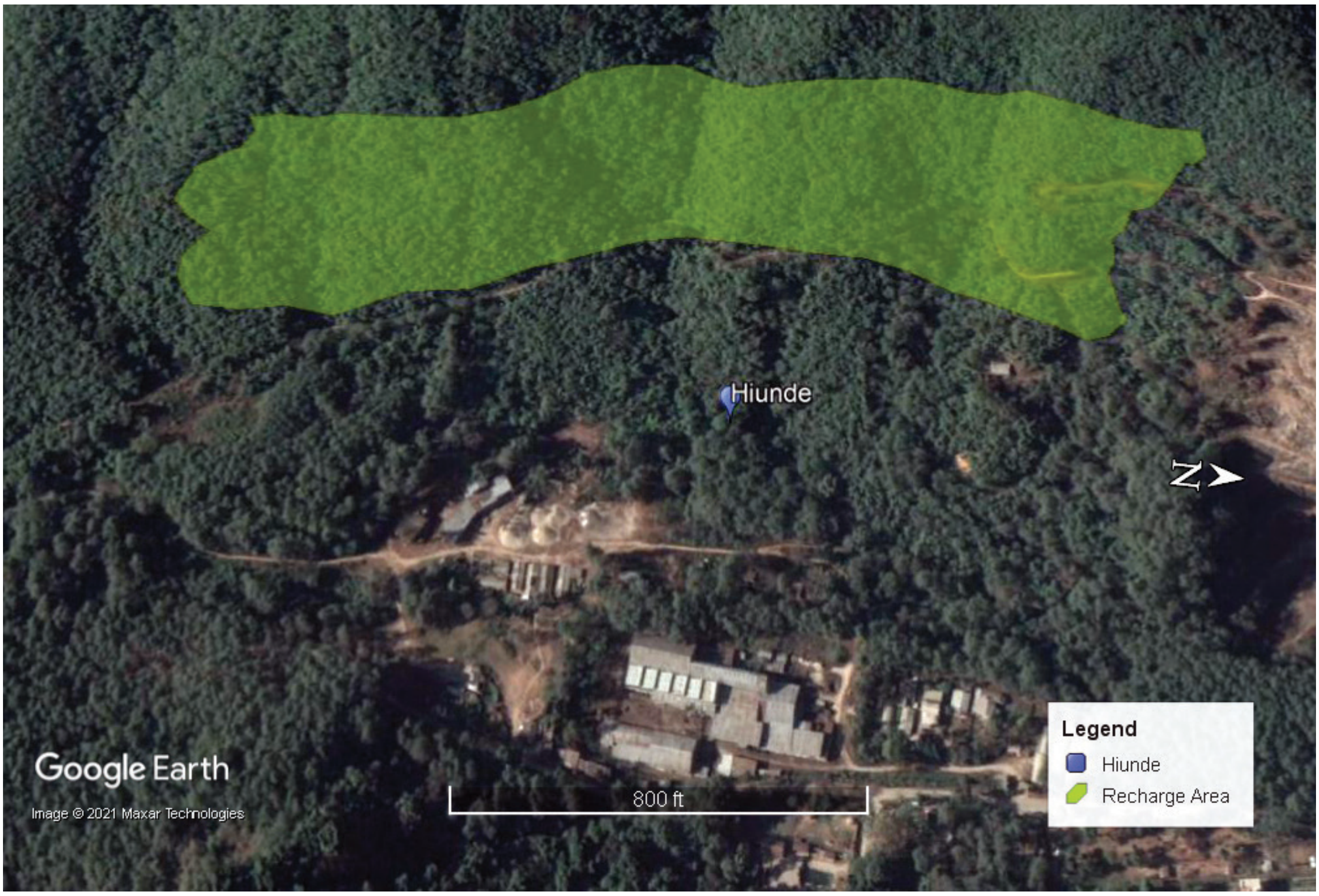


FIGURE 30 THE RECHARGE AREA FOR HIUENDE



The spring's recharge area is simply based on the concepts of a dip slope and escarpment slope. Considering the dip of the sandstone, the recharge area covers both the dip slope and escarpment slope to certain extent. The identified recharge area considers primarily the openings along the bedding planes (Figures 32 and 33).

3.4.7 Kuna Khola 1 and 2

Kuna Khola has one of the highest volumes of discharge among the springs in the Godavari springshed, and is hence tapped by people to meet both their domestic and drinking water needs. In fact, its discharge is so strong during the monsoon that it gets difficult for anyone to even reach its source.

FIGURE 31 GOOGLE EARTH IMAGE OF DEVITHAN SPRING WITH GEOLOGICAL OVERLAY

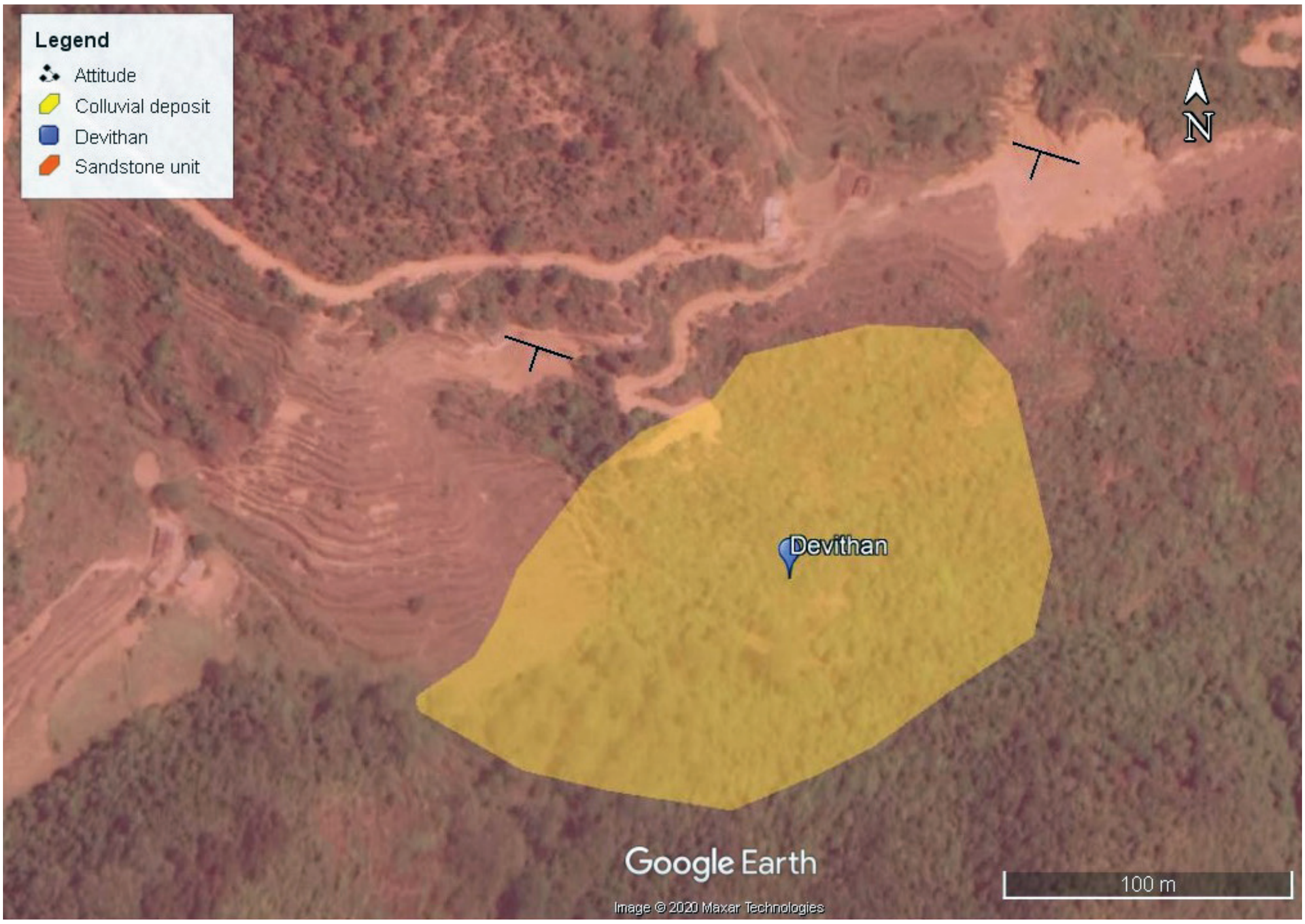


FIGURE 32 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF DEVITHAN SPRING WITH THE RECHARGE AREA DEMARCATED

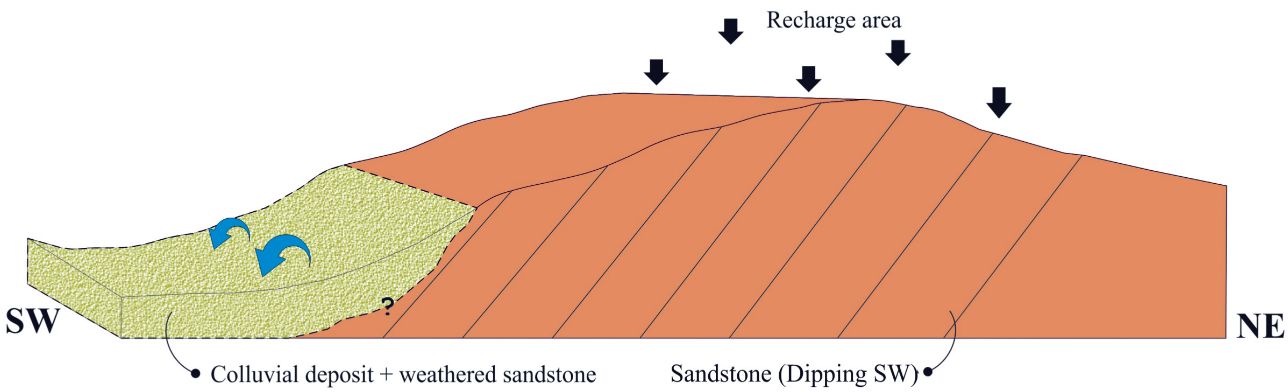


FIGURE 33 THE RECHARGE AREA FOR DEVITHAN

The geological set-up in the vicinity of Kuna Khola is predominantly a folded sequence of fractured limestone, interbedded with marl and quartzite (Figure 34). The spring seems to emerge along one of the limbs of an anticline through fractures. The axis of its fold follows the same trend NW–SE as that of the regional fold axis. One fracture set dips in the northeasterly direction trending NW–SE while the other dips in the southeasterly direction, trending NE–SW (Figure 35). The spring emerges out through this fractured network. However, the fractured limestone alone is certainly not able to support such a high discharge. Other locations encountered in the same limestone unit exhibit karstic features which could also be present in the case of Kuna Khola, and could be a factor enabling its high discharge.

The recharge area for Kuna Khola spring (Figure 36) was identified considering the fracture trends and dipping limb along the spring. As in the case of Naudhara spring (see subsection 3.4.4), Kuna Khola's recharge area might be even larger, either as a single zone or have multiple micro charging points due to the karstic properties of limestone. Locating these micro sources was not feasible due to the presence of dense vegetation.

3.4.8 Gauri Kunda

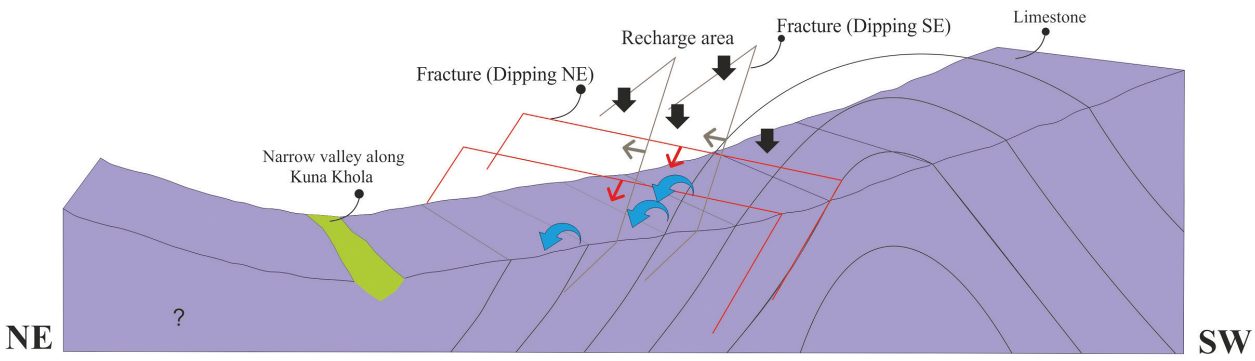
Gauri Kunda is among the unique springs in the Godavari springshed. It abruptly ran dry after the 2015 earthquake that took place in Nepal. The challenge it poses now is whether it can be revived by undertaking recharge interventions through a hydrogeological approach.

Gauri Kunda has a geological setting (Figure 37) similar to that of Godavari Kunda. Gauri Kunda, however, used to emerge through a weathered rock section whose thickness is difficult to ascertain. The underlying geology comprises a folded sequence of limestone and sandstone, with the fold's axis trending in the NE–SW direction. Thus, the spring used to probably receive water from two storages, namely the weathered rock section with limited storage, and the underlying folded limestone unit that is karstic in nature (Figure 38). The spring is thus a combination of a depression and karstic type.

The spring will revive provided that the path in which its groundwater flowed has not been disturbed by the earthquake. If it has, the interventions to recharge it may not prove entirely beneficial.

FIGURE 34 GOOGLE EARTH IMAGE OF KUNA KHOLA SPRING WITH GEOLOGICAL OVERLAY

FIGURE 35 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF KUNA KHOLA WITH THE RECHARGE AREA DEMARCATED



The recharge area has been identified (Figure 39) considering the fact that the spring is primarily supported by folded-karstic limestone. The weathered rock, which has a limited storage capacity, will receive recharge from the underlying limestone, eventually supporting the spring discharge.

3.4.9 Godavari Kunda

Godavari Kunda is considered a holy spring by communities in the area. It is a perennial spring with one of the highest discharge volumes in the Godavari region. It is part of a similar hydrogeological set-up as that of Sungure Khola. The spring emerges at the base of a hill through a fracture opening making it a classic case of a fracture spring (Figure 40). However,

FIGURE 36 THE RECHARGE AREA FOR KUNA KHOLA

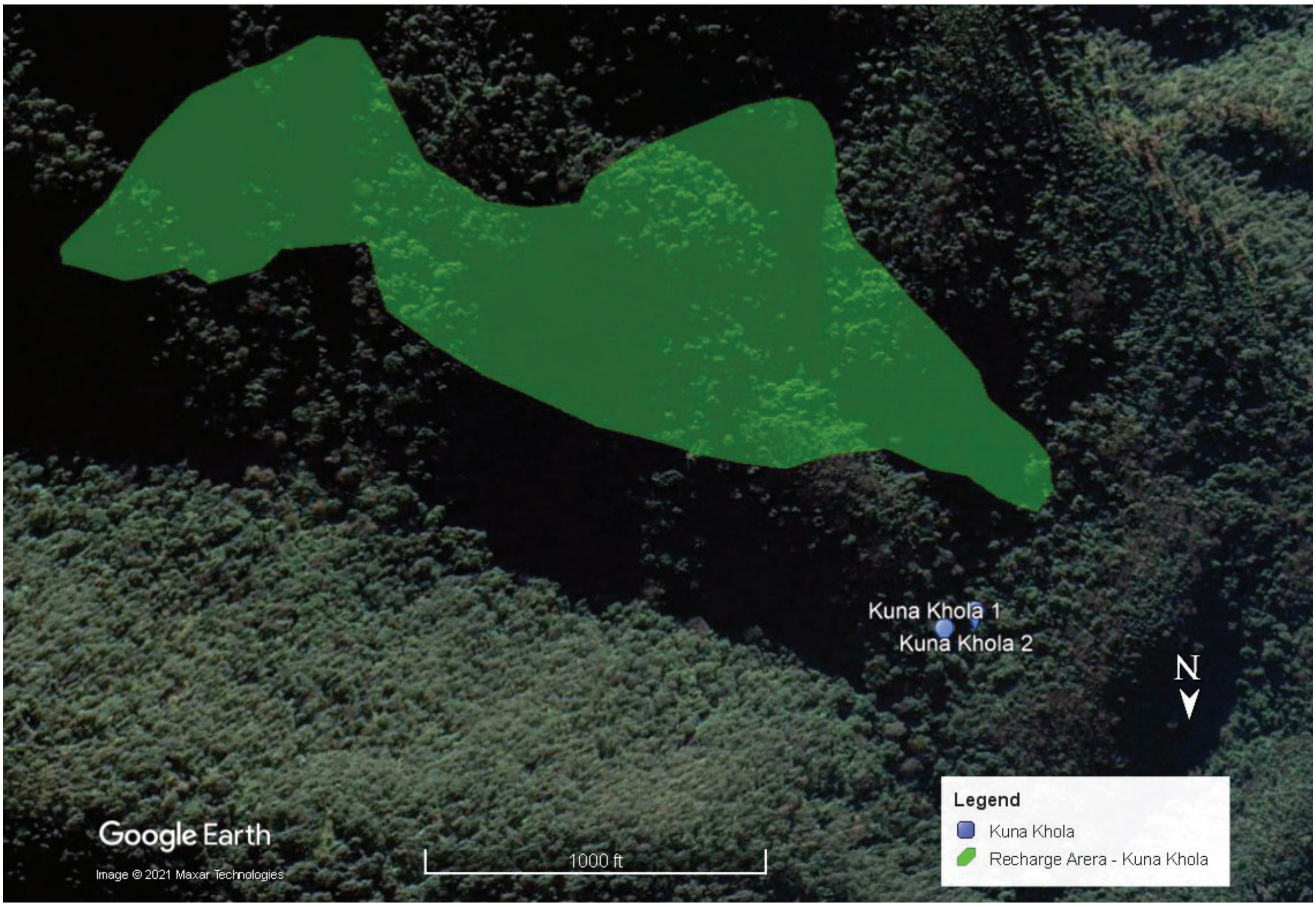


FIGURE 37 GOOGLE EARTH IMAGE OF GAURI KUNDA WITH GEOLOGICAL OVERLAY

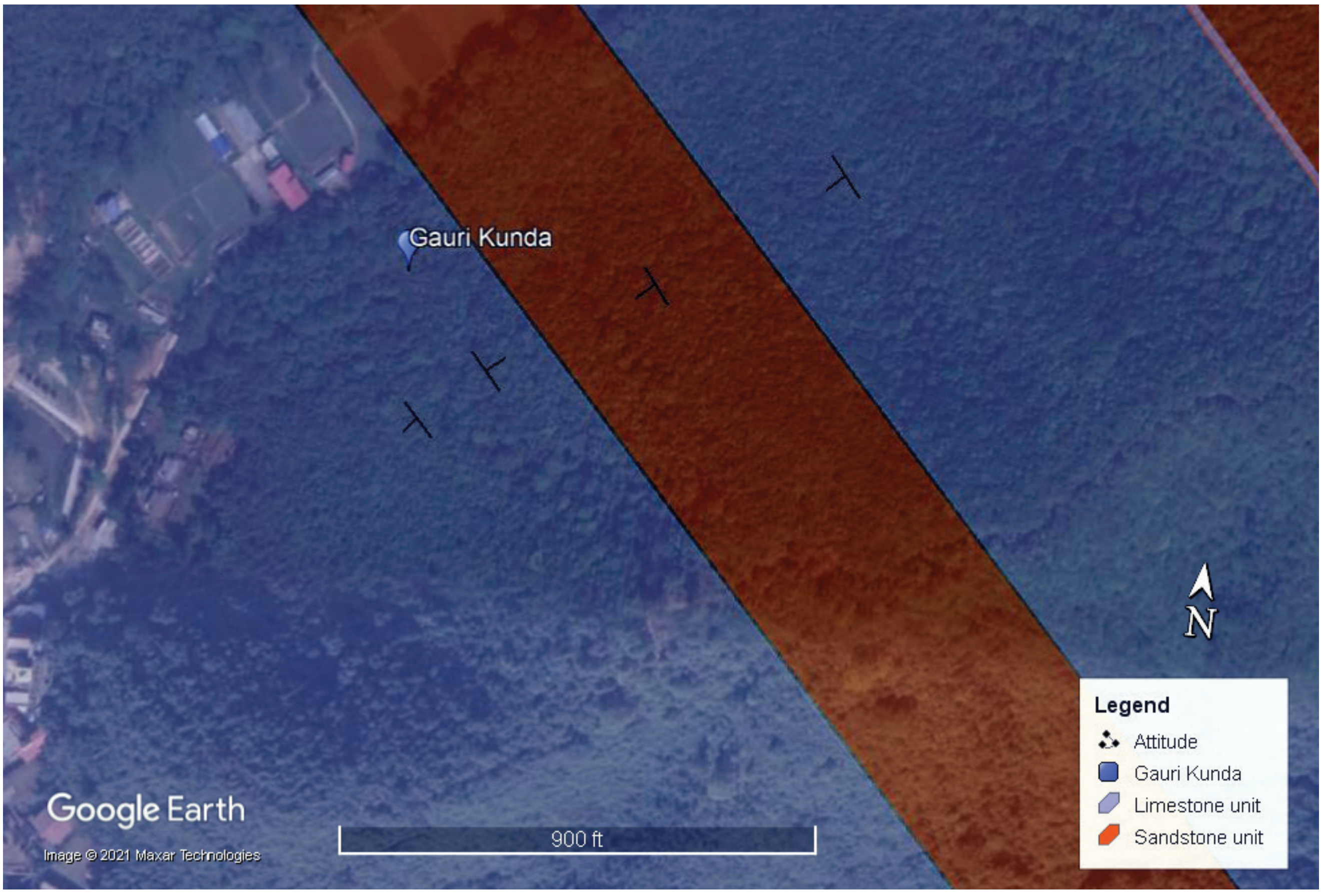


FIGURE 38 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF GAURI KUNDA WITH THE RECHARGE AREA DEMARCATED

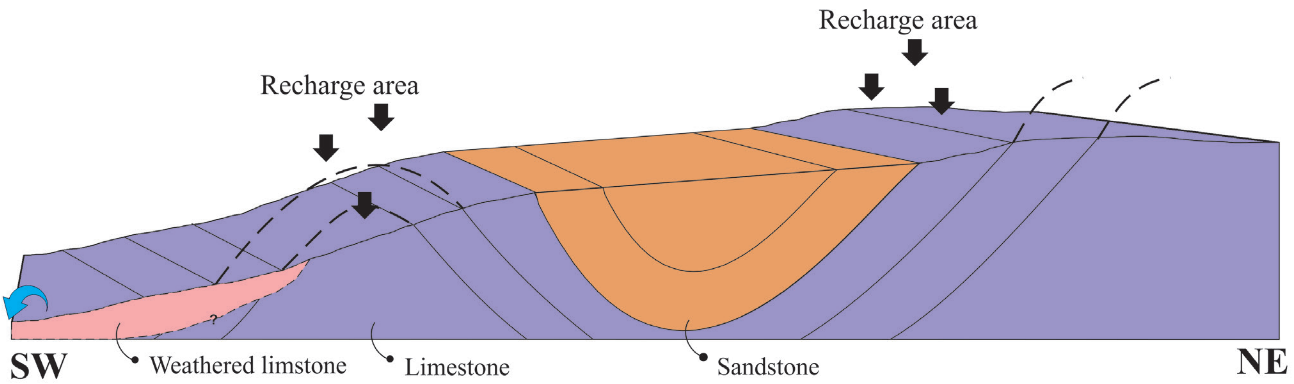
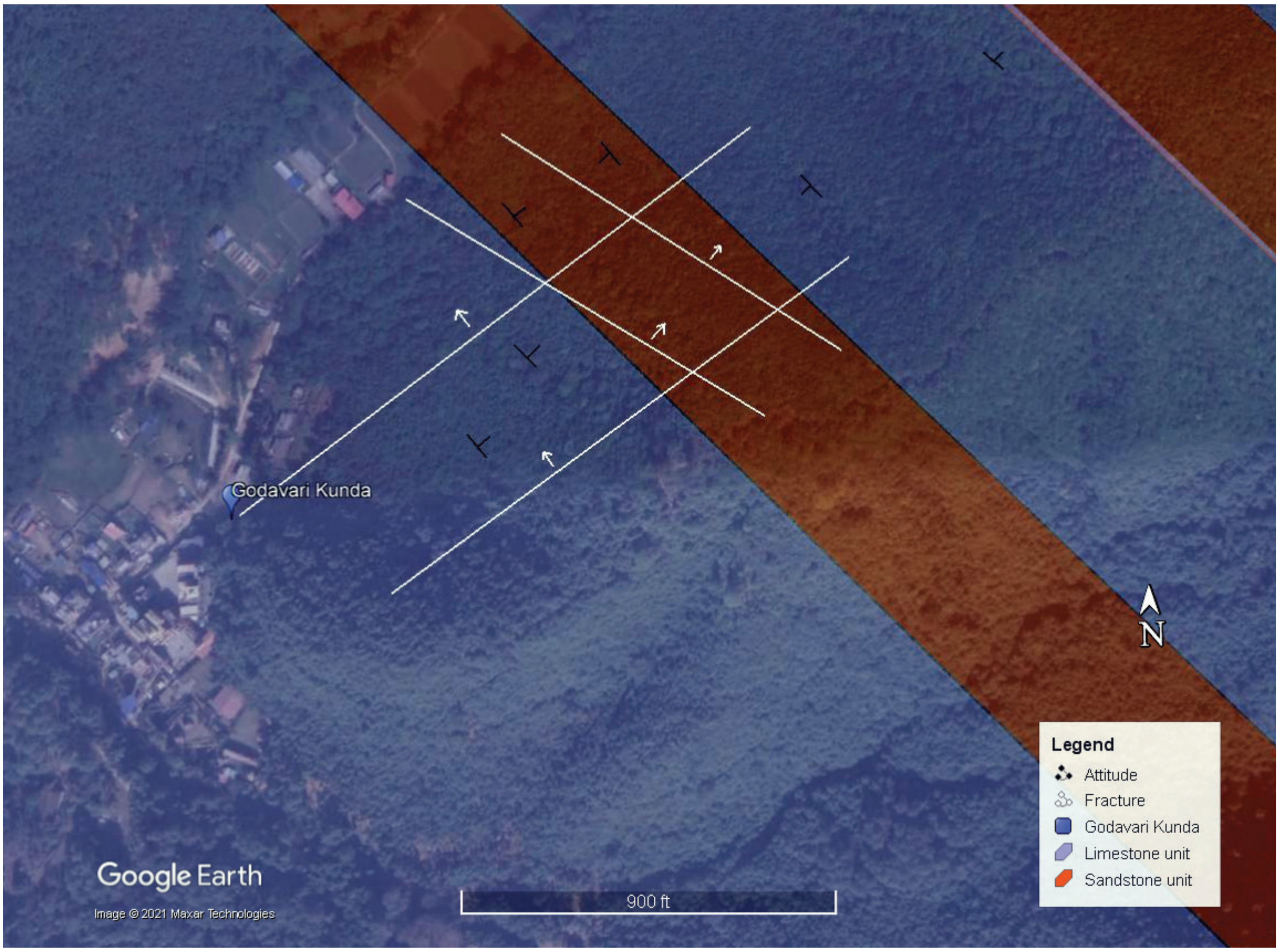


FIGURE 39 GOOGLE EARTH IMAGE SHOWING THE RECHARGE AREA FOR GAURI KUNDA

FIGURE 40 GOOGLE EARTH IMAGE SHOWING THE RECHARGE AREA FOR GAURI KUNDA



its discharge history and present trends indicate a large storage which the fracture system alone might not be able to support. Certain formations in and around the spring exhibit karstic features, and they probably add to the storage, which enables a high spring discharge even during the non-monsoon period.

There are two dominant fracture networks present in the folded sequence of limestone and sandstone, one trending NE–SW and dipping in a northwesterly direction, the other trending NW–SE and dipping to the northeast. However, the prominent fracture network through which spring emerges is the one dipping northwest, which is clearly seen at the spring's location (Figure 41).

The recharge area for Godavari Kunda is identified in two zones based on fracture trends and lithological boundaries (Figure 42). The larger recharge area takes into consideration both the fracture network and the limestone unit which forms a syncline. The smaller recharge area also accounts for a smaller syncline measured in the same limestone unit. The karstic features in limestone will additionally incorporate more storage supporting the spring.

FIGURE 41 HYDROGEOLOGICAL CONCEPTUAL LAYOUT OF GODAVARI KUNDA WITH RECHARGE AREA DEMARCATED

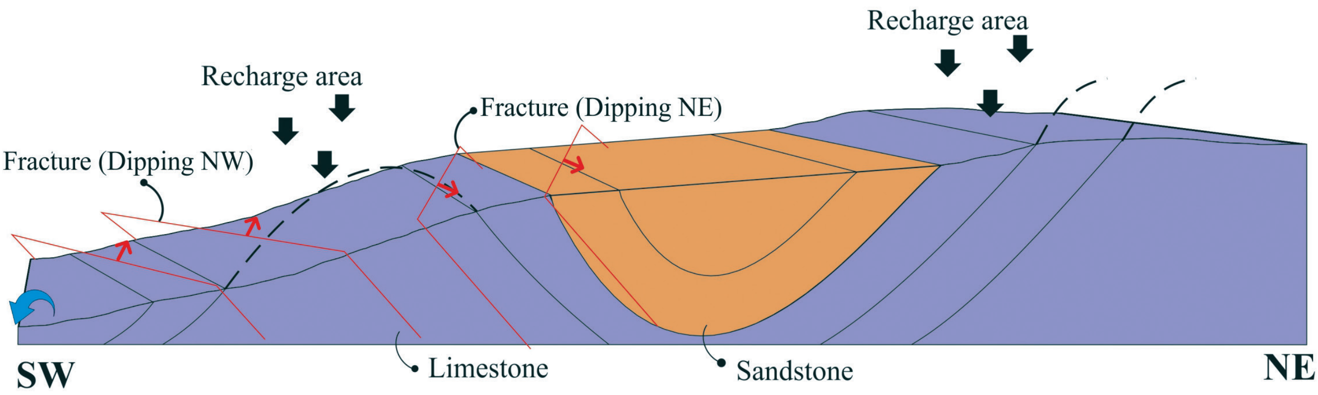


FIGURE 42 RECHARGE AREA FOR GODAVARI KUNDA

SECTION IV

Conclusions and way forward

It is evident that the spring water resources in the Godavari area in Nepal are under stress due to the growing demand for water. Four of the forty springs in the area have dried up due to the earthquake of 2015, one spring (Gauri Kunda) has become seasonal post-earthquake, and a few small, low-discharge springs show decreasing discharge. Some dried springs were also reported during the survey that are located outside the study area. The WUGs reported a reduced availability of water due to springs drying; they are unable to address the growing demand for water from an increasing population and growing number of industries. As a response, alternative spring sources have been identified and added to the existing system. For instance, the Hiuende spring was used by the Thaiba and Harisiddhi WUGs and dried due to the 2015 earthquake; a new source, Gwalindaha, was added to the system.

The significant increase in spring discharge during the monsoon indicates that dense forest cover and the presence of permeable strata in the Godavari watershed have contributed to good groundwater recharge. However, although the majority of monitored springs show more discharge in the last two-and-a-half years, it may be a short-term phenomenon; a few other springs have dried up or show a reduced discharge. Furthermore, long-term annual rainfall data shows it is decreasing significantly, by about 25–30 mm per year, validating the community's perceptions regarding a decline in spring discharge.

Microbiological analyses show higher levels of total coliform and *E. coli* during the early monsoon than in the winter in most of the springs. The *E. coli* level was above the detection limit (>8,000 CFU/100ml) in Devithan in June. Sungure Khola is free from *E. coli* in both seasons.

Small WUGs in the region generally do not treat their water, whereas medium and large WUGs had some sort of water treatment system. Most WUGs treat their water by adding chlorine intermittently, though a few also use slow sand filtration and desiltation. One should point out that testing for water quality is itself done on an ad hoc basis by all the water supply schemes here. In order to ensure safe and clean drinking water for all, a significant improvement in the frequency of its testing and treatment is essential.

In order to address the crucial issue of the longer-term decreasing water availability and quality, recharge measures should be adopted to revive drying and dried springs by implementing conservation and rainwater harvesting practices. Rainwater harvesting structures contribute to increasing infiltration, and consequently help raise the water table of the underground aquifer. Forest conservation, appropriate tree plantation, and management measures such as restricting open defecation, forest fires, free grazing, and dumping garbage in the springshed will help improve water quality and quantity. This can be achieved by sensitizing the local community about the hydrogeology that governs a springshed. In addition, the local youth, women and men both, can be trained as para-hydrogeologists who could sensitize the local community about springshed management and also help identify the recharge zones of critical springs in their locality and collect essential spring water data. Hence, along with technical measures, the governance systems for managing springs also need to be strengthened taking into account gender and social inclusion. A locally appropriate gender equality and social inclusion (GESI) framework would help in the better design of intervention activities.

The condition of the forests in Godavari and Chapakharka has gradually improved after they were handed over to local communities, which contributed to a healthy ecosystem and spring revival. But there are open spaces in the identified recharge zones that fall under community forests. In such open spaces, native tree species can be planted and rainwater harvesting structures such as shallow ponds, trenches, pits, and wetlands constructed to enhance spring discharge and improve water quality.

Springs are also very important for biodiversity and wildlife habitats. The depletion of spring resources not only impacts people but also the rich flora and fauna found in the Godavari Landscape. For instance, nearly 57 species of dragonfly have been reported in 2016 from the Godavari area (Conniff, 2020). Their survival depends on clean water sources, including springs, and therefore the depletion of springs in terms of quantity and quality of their water has an adverse impact on dragonflies and numerous other species. Hence, it is important that wildlife habitat and biodiversity conservation also be made an integral part of springshed management. These aspects should be further understood and better integrated into a socioecological resilience framework for the revival of springs.

An initiative to engage multiple stakeholders in springshed management has been initiated through the Godavari Landscape Journey. It is a participatory process of bringing together multidisciplinary/intersectoral teams of stakeholders (Rathore et al., 2019) for developing a shared understanding, vision, and actions to secure the uniqueness of the Godavari Landscape, with the full ownership of stakeholders at different levels. The activities undertaken during the journey allow the participants to identify the key prevailing issues within the Landscape, assimilate and integrate knowledge from various disciplines, and take ownership and commit to addressing the key issues identified in synchronization. The key aim of the Godavari Landscape Journey is to build a shared understanding and vision for the Godavari Landscape and develop the ICIMOD Knowledge Park as a key hub for knowledge and skill dissemination.

The first Godavari Landscape journey was held in November 2016 and the fourth in June 2018. In between the first and the fourth landscape journeys, information on the Godavari springs and their status, issues, and the relevant interventions required in identified recharge areas towards improving water quality and quantity were shared with key stakeholders of the region in 2019.

A few critical springs that have been affected by the earthquake of 2015 have also been identified, such as Gauri Kunda and Hiuende Mul. These dried springs and other critical springs require actions to help them recharge, interventions which are also gender and socially inclusive. This can be achieved in close collaboration with the Godavari municipality, the respective wards, water and land users' groups, research institutions, and other stakeholders.

References

Conniff, K. (2020). Nepal Odonata: A Photocollection of Dragonflies and Damselflies from Nepal with Species Checklist, https://odonatanepal.blogspot.com/ (accessed 10 November 2020)

Featherstone, J. D. B. (1999). Prevention and reversal of dental caries: Role of low level fluoride. *Community Dentistry and Oral Epidemiology*, *27*(1), 31–40. DOI:10.1111/j.1600-0528.1999.tb01989.

Fewtrell, L. (2004). Drinking water nitrate, methemoglobinemia, and global burden of disease: A discussion. *Environmental Health Perspectives*, *112*(14), 1371–1374. DOI: 10.1289/ehp.7216.

Gentle, P. & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science & Policy*, *21*, 24–34. https://doi.org/10.1016/j.envsci.2012.03.007

Gisbert, J., Vallejos, A., González, A. & Pulido-Bosch, A. (2009). Environmental and hydrogeological problems in karstic terrains crossed by tunnels: A case study. *Environmental Geology*, *58*(2), 347–357. https://doi.org/10.1007/s00254-008-1609-1

John, R. C. M., Kitheka, J. U. & Mwangi, M. (2017). Assessment of the effects of deforestation on springs: A case study of Nuu/Mutaitho Hills springs in Kitui County. *International Journal of Science and Research*, *6*(1), 1889–1898. https://doi.org/10.21275/art20164423

JVS and GWP (2017). *Impact of Earthquake on Water Resources in Selected Earthquake Hit Areas: Adaptation Practices and Planning in Namobuddha Municipality , Kavre-palanchowk District*. Kathmandu: Jalsrot Vikas Sanstha and GWP Nepal

Khadka, K. & Rijal, M. L. (2020). Hydrogeochemical assessment of spring water resources around Melamchi, Central Nepal. *Water Practice and Technology, 15(3),* 748-758. Doi: 10.2166/wpt.2020.066

Malla, G. (2009). Climate change and its impact on Nepalese agriculture. *Journal of Agriculture and Environment*, *9*, 62–71. https://doi.org/10.3126/aej.v9i0.2119

Merz, J., Nakarmi, G., Shrestha, S. K., Dahal, B. M., Dangol, P. M., Dhakal, M. P., Dongol, B. S., Sharma, S., Shah, P. B. & Weingartner, R. (2003). Water: A scarce resource in rural watersheds of Nepal's Middle Mountains. *Mountain Research and Development*, *23*(1), 41–49. https://doi.org/10.1659/0276-4741(2003)023[0041:wasrir]2.0.co;2

Molden, O., Griffin, N. & Meehan, K. (2016). The cultural dimensions of household water security: The case of Kathmandu's stone spout systems. *Water International*, *41*(7), 982–997. https://doi.org/10.1080/02508060.2016.1251677

Molden, O. C. & Meehan, K. (2018). Sociotechnical imaginaries of urban development: Social movements around "traditional" water infrastructure in the Kathmandu Valley. *Urban Geography*, *39*(5), 763–782. https://doi.org/10.1080/02723638.2017.1393921

NDWQS (2005). National Drinking Water Quality Standards and Directives. Kathmandu: Ministry of Physical Planning and Works. Retrieved from http://mowss.gov.np/assets/uploads/files/NDWQS_2005_Nepal.pdf

Negi, G. C. S. & Joshi, V. (2002). Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. *Mountain Research and Development*, *22*(1), 29–31. https://doi.org/10.1659/0276-4741(2002)022[0029:dwiado]2.0.co;2

NITI Aayog (2018). *Report of Working Group I: Inventory and Revival of Springs in the Himalayas for Water Security*. New Delhi: Niti Aayog, Government of India.

Pokhrel, G & Rijal, M. L. (2020). Seasonal Variation of Springwater In-Situ Parameters in the Bhusundi Catchment, Gorkha, Nepal. *Journal of Institute of Science and Technology, 25(1),* 45-51. Doi: https://doi.org/10.3126/jist.v25i1.29450

Rathore, B. M. S., Shakya, B., Rawal, R., Semwal, R., Kotru, R. & Dorji, T. (2019). *Landscape journey: A process tool for practitioners*. Kathmandu: ICIMOD. https://lib.icimod.org/record/34636

Scott, C. A., Zhang, F., Mukherji, A., Immerzeel, W., Mustafa, D. & Bharati, L. (2019). Water in the Hindu Kush Himalaya. In P. Wester, A. Mishra, A. Mukherjee, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* (pp. 257–299). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-319-92288-1

Sharma, B., Nepal, S., Gyawali, D., Pokharel, G. S., Wahid, S., Mukherji, A., Acharya, S. & Shrestha, A. B. (2016). *Springs, storage towers, and water conservation in the midhills of Nepal*. ICIMOD Working Paper 2016/3. Kathmandu: ICIMOD. https://doi.org/10.13140/RG.2.1.4142.4886

Sharma, G., Pradhan, N., Sharma, D. P., Luitel, M., Barola, Y., Luitel, K. K. & Nyima, K. (2019). *Conserving springs as climate change adaptation action: Lessons from Chibo–Pashyor watershed, Teesta River Basin, Kalimpong, West Bengal, India*. ICIMOD Working Paper 2019/2. Kathmandu: ICIMOD. https://lib.icimod.org/record/34553

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*. Kathmandu: ICIMOD. https://doi.org/978 92 9115 606 1

Shrestha, S., Semkuyu, D. J. & Pandey, V. P. (2016). Assessment of groundwater vulnerability and risk to pollution in Kathmandu Valley, Nepal. *Science of the Total Environment*, *556*, 23–35. https://doi.org/10.1016/j.scitotenv.2016.03.021

Siddique, M. I., Desai, J., Kulkarni, H. & Mahamuni, K. (2019). Comprehensive report on springs in the Indian Himalayan region: Status of springs, emerging issues and responses. ACWADAM Report ACWA/Hydro/2019/H88. Pune: ACWADAM.

Stőcklin, J. (1980). Geology of Nepal and its regional frame: Thirty-third William Smith Lecture. *Journal of the Geological Society*, *137*(1), 1–34. https://doi.org/10.1144/gsjgs.137.1.0001

Stőcklin, J. & Bhattarai, K. D. (1977). *Geology of Kathmandu Area and Central Mahabharat Range, Nepal*. Kathmandu: Department of Mines and Geology, Government of Nepal.

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*, *32*(1), 62–72. https://doi.org/10.1659/mrd-journal-d-11-00079.1

Thapa, B. R., Ishidaira, H., Pandey, V. P. and Shakya, N. M. (2016). Impact Assessment of Gorkha Earthquake 2015 on Portable Water Supply in Kathmandu Valley: Preliminary Analysis. *Journal of Japan Society of Civil Engineers*, 72(4), 61-66.

Tiwari, P. C. & Joshi, B. (2015). Climate change and rural out-migration in Himalaya. *Change and Adaptation in Socio-Ecological Systems*, *2*(1), 8–25. https://doi.org/10.1515/cass-2015-0002

Trainer, F. W. (1969). Drainage density as an indicator of base flow in part of the Potomac River basin. Washington, D.C.: US Geological Survey Professional Paper 650. Washington, D.C.: USGS.

Valdiya, K. S. & Bartarya, S. (1989). Diminishing discharges of mountain springs in a part of Kumaun Himalaya. *Current Science*, *58*(8), 417–426.

Vincenzi, V., Gargini, A. & Goldscheider, N. (2009). Using tracer tests and hydrological observations to evaluate effects of tunnel drainage on groundwater and surface waters in the Northern Apennines (Italy). *Hydrogeology Journal*, *17*(1), 135–150. https://doi.org/10.1007/s10040-008-0371-5

Annexes

Annex 1: Details of the springs inventoried in the study area

Name	Code	Latitude (N)	Longitude (E)	Elevation (m)	Seasonality	Spring type	Users	Uses
GKP-01	GKP-1	27.59316667	85.38744444	1,547	Perennial	Depression	Herbarium	Gardening
GKP-02	GKP-2	27.59288889	85.38675	1,561	Dried	Depression	–	–
Thulo Seem	GKP-3	27.59380556	85.38841667	1,578	Perennial	Depression	Botanical garden	Drinking, gardening
Chisopani	GKP-4	27.59097222	85.39441667	1,680	Perennial	Depression	Picnic spot, ICIMOD Godavari Knowledge Park	Domestic use
Tallo Sungure	GKP-5	27.59366667	85.3895	1,600	Perennial	Depression	Botanical garden, gumba (monastery), houses at Godavari Kunda area, picnic spot	Drinking
Sungure Khola 3	GKP-6	27.58888889	85.39725	1,702	Perennial	Depression + Fracture	NA	NA
Sungure Khola 1	GKP-7	27.58869444	85.39755556	1,717	Perennial	Fracture	Fish pond (Godavari Knowledge Park)	Fishery
Sungure Khola 2	GKP-8	27.58847222	85.39730556	1,727	Perennial	Fracture	Godavari WUG	DWS
Setokokaro 1	GKP-9	27.58286111	85.3965	1,993	Perennial	Depression + Fracture	Research centre, Godavari WUG	DWS
Naudhara	GKP-10	27.588	85.37944444	1,613	Perennial	Depression + Karst	Godavari WUG	DWS
Kuna Khola 4	GKP-11	27.58061111	85.37819444	1,684	Perennial	Depression + Fracture	Godavari WUG	DWS
Hiuende	GKP-12	27.58763889	85.37675	1,601	Dried	Depression + Fracture	Thaiba and Harisiddhi WUG	DWS
Devithan 1	GKP-13	27.59647222	85.40922222	1,989	Perennial	Depression + Fracture	Chapakharka WUG	Drinking
Devithan 2	GKP-14	27.59633611	85.40951389	1,986	Dried	Depression	–	–
Muldol	GKP-15	27.59627778	85.41072222	1,963	Perennial	Depression	4 HHs	Drinking
Saatkaredol	GKP-16	27.59680556	85.41291667	1,939	Perennial	Depression	Not used	Not used

Name	Code	Latitude (N)	Longitude (E)	Elevation (m)	Seasonality	Spring type	Users	Uses
Khalte	GKP-17	27.59858333	85.41308333	1,947	Perennial	Depression	4 HHs	Drinking, irrigation
GKP-18	GKP-18	27.59897222	85.41222222	1,973	Dried	Depression	–	–
GKP-19	GKP-19	27.60016111	85.41650278	1,945	NA	NA	NA	NA
GKP-20	GKP-20	27.59876389	85.41866667	1,926	NA	NA	NA	NA
GKP-21	GKP-21	27.59829167	85.41715278	1,924	NA	NA	NA	NA
Sildada Mul	GKP-22	27.59866667	85.41008333	2,008	Perennial	Depression	Khalte	Drinking
Tripyani Khola	GKP-23	27.60227778	85.40861111	1,977	Perennial	Depression	Thingtol (15 HHs)	Drinking
Syangtol Mul	GKP-24	27.60283333	85.40688889	2,038	Perennial	Depression	Syangtol (18 HHs)	Drinking
Kuna Khola 1	GKP-25	27.57136111	85.37866667	1,873	Perennial	Fracture + Karst	Thaiba and Harisiddhi WUGs	DWS
Kuna Khola 2	GKP-26	27.57122222	85.37838889	1,899	Perennial	Karst	Thaiba and Harisiddhi WUGs	DWS
Kuna Khola 3	GKP-27	27.57280556	85.37861111	1,855	Perennial	Depression	NA	NA
GKP-28	GKP-28	27.59283333	85.38508333	1,594	Perennial	Depression	NA	NA
Setokokaro 2	GKP-29	27.58501111	85.38943056	1,764	Perennial	Depression + Fracture	Godavari WUG	DWS
Setokokaro 3	GKP-30	27.58502778	85.38897222	1,716	Perennial	Depression	Godavari WUG	DWS
Gauri Kunda	GKP-31	27.59952	85.38835	1,555	Seasonal	Depression + Karst	Kalyechaur WUG, Kitachaur WUG, Tanker	DWS
GKP-32	GKP-32	27.60301	85.39423	1,634	Perennial	Depression	NA	NA
Patale Muldol	GKP-33	27.60657	85.39787	1,735	Perennial	Depression	Kalyechaur WUG	DWS
Godavari Kunda	GKP-34	27.59769	85.38671	1,518	Perennial	Fracture + Karst	Godamchaur WUG, Godavari WUG, tankers	DWS
Mrigapalan spring 1	GKP-35	27.60422	85.39504	1,612	Perennial	Depression	Kalyechaur WUG, Dol Bhangeri WUG, Kitachaur WUG	DWS
Mrigapalan spring 2	GKP-36	27.60343	85.39426	1,621	Perennial	Depression	Kalyechaur WUG, Bhangeri WUG, Kitachaur WUG	DWS
GKP-37	GKP-37	27.58269444	85.41387222	2,037	NA	NA	NA	NA
Panighat Mul	GKP-38	27.57967778	85.40410556	2,218	NA	NA	NA	NA
Wetland	GKP-39	27.59338889	85.38833333	1,576	Perennial	Depression	Not used	Not used
Chhyang Chhyang Khola	GKP-40	27.583717	85.414100	1,889	Perennial	Depression	Lakuri Bhanjyang WUG	DWS

Notes: NA – Not available; HHs – Households; DWS – Drinking water supply; WUG – Water user group

Annex 2: Water user groups and their sources of water

Water user groups	Sources of water
Godavari Khanepani Tatha Sarsafai Upabhokta Samiti	Naudhara, Kuna Khola 4, Setokokaro 1 and 2, Sungure Khola, Godavari Kunda
Harisiddhi Khanepani Tatha Sarsafai Upabhokta Samiti	Kuna Khola 1and 2, Hiuende, Gwalindaha
Thaiba Khanepani Tatha Sarsafai Upabhokta Samiti	Kuna Khola 1 and 2, Hiuende, Gwalindaha
Godamchaur Khanepani Ayojana – Mul Upabhokta Samiti	Spring/river (source unclear) (in Dhad), Lamo Kunda
Kalyechaur Khanepani Tatha Sarsafai Upabhokta Samiti	Patale Muldol, Mrigapalan 1 and 2, Gauri Kunda
Dol Bhangeri Khanepani Tatha Sarsafai Upabhokta Samiti	Mrigapalan 1 and 2
Swoti Kuwa Khanepani Tatha Sarsafai Upabhokta Samiti	Swoti Kuwa, Gwade Seem
Bishankhu Narayan Khanepani Tatha Sarsafai Upabhokta Samiti	Dudako Khola, Chetako Dol
Mulko Khanepani Samuha	Mulko pani
Dhobi Khola Tindhara Khanepani Tatha Sarsafai Upabhokta Samiti	Tindhara Mul
Bistachhap Khanepani Upabhokta Samuha	Simbhanjyang Mul
Kitachaur Khanepani Tatha Sarsafai Upabhokta Samiti	Gauri Kunda, Godavari Khola (from Mrigapalan)
Siddhipur Khanepani Tatha Sarsafai Upabhokta Sanstha	Godavari Khola
Imadol Khanepani Tatha Sarsafai Upabhokta Samiti	Godavari Khola
Lubhu Khanepani Tatha Sarsafai Upabhokta Sanstha –Tallo Dobhan Khanepani Yojana	Lubu Khola (a major tributary of Godavari Khola)
Chapakharka Khanepani Tatha Sarsafai Upabhokta Samiti and Sashambhu Khanepani Tatha Sarsafai Upabhokta Samiti	Devithan, Khahare (Spring)
Lakuribhanjyang Khanepani Ayojana – Lamatar	Chyang Chyang Khola
Lakuribhanjyang Khanepani Ayojana – Bishankhu	Chyang Chyang Khola
Sungure Khola Khanepani Upabhokta Samuha	Tallo Sungure
Five local water supply systems	Springs in Chapakharka

About ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD), is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

REGIONAL MEMBER COUNTRIES

AFGHANISTAN BANGLADESH BHUTAN CHINA
INDIA MYANMAR NEPAL PAKISTAN

Corresponding author

Madhav Prasad Dhakal
madhav.dhakal@icimod.org

Published by
International Centre for Integrated Mountain Development (ICIMOD)
GPO Box 3226, Kathmandu, Nepal

ISBN 978 92 9115 733 4 (electronic)

DOI

Citation
Dhakal, M.P., Khadka, K., Pokhrel, G., Desai, J., Kingsley, C., Barola, Y., & Bhuchar. S. (2021). *Springs in the Godawari landscape, Nepal. Working paper.* ICIMOD.

Australian AID

ICIMOD gratefully acknowledges the support of its core donors: the Governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden, and Switzerland.

International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal
T +977 1 5275222 | **E** info@icimod.org | **www.icimod.org**

ISBN 978 92 9115 733 4 (electronic)
DOI