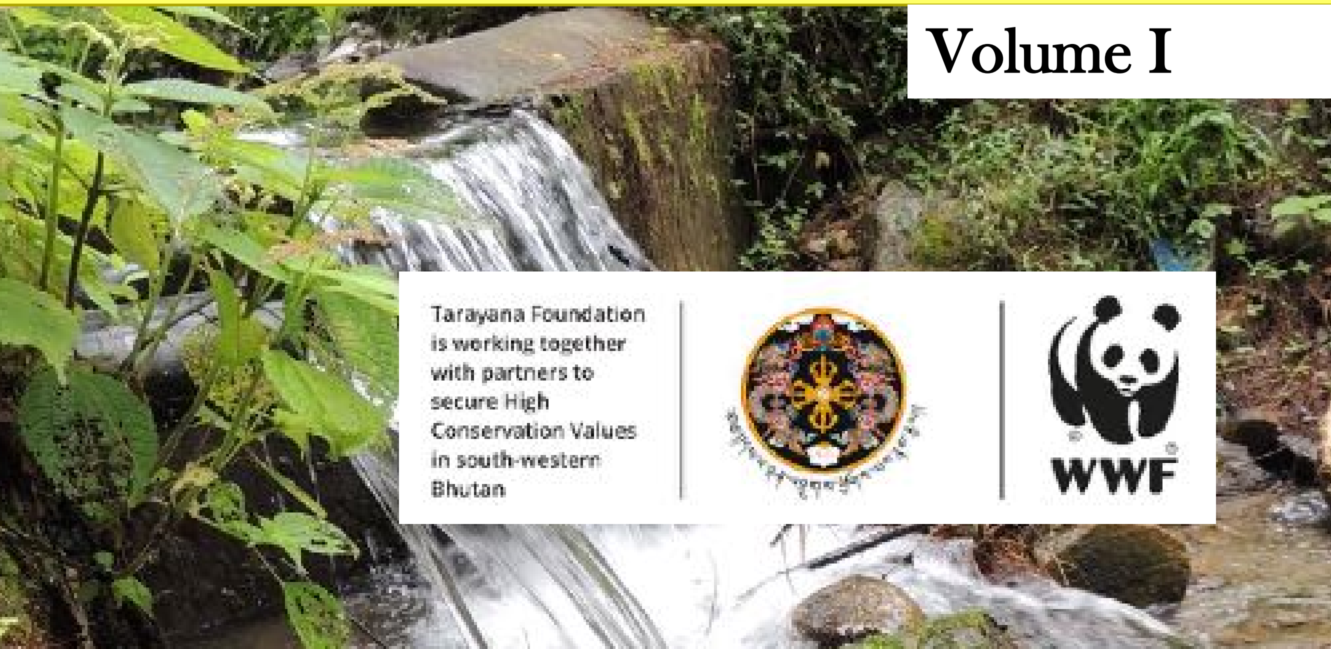
Springshed: Identifying Recharge Areas of Drying Springs and Lakes with Water Quality in Southwestern Bhutan

Volume I



Tarayana Foundation is working together with partners to secure High Conservation Values in south-western Bhutan

Springshed: Identifying Recharge Areas of Drying Springs and Lakes with Water Quality in Southwestern Bhutan

This book is dedicated to the grassroots communities who are on a journey of growth and empowerment with your unfaltering support and partnership. We at Tarayana reaffirm our commitment to Service from the Heart in commemoration of Tarayana's 19th Anniversary.

Springshed: Identifying Recharge Areas of Drying Springs and Lakes with Water Quality in Southwestern Bhutan

Tarayana Foundation
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FOREWORD

The Royal Government of Bhutan launched a Water Flagship Programme in 2020 to ensure access to quality water for drinking and irrigation, and also to contribute to SDG goal 6- Clean water and sanitation for all. This study complements the National Water Flagship Programme objective to ensure uninterrupted access to quality drinking and irrigation water for all households living in the study area.

The study area includes protection of critical watersheds of south-western Bhutan with focus on the demarcation of recharge areas of drying lakes and springs as a first step for intervention. Some studies have shown that demarcation and strategic interventions in the recharge areas of critical watersheds make substantive differences in the flow of spring water and the health of local lakes. In the past, water resource management efforts did not pay much attention to the conservation and protection of recharging areas as an important aspect of water source.

The Living Landscapes - Securing High Conservation Values project in south-western Bhutan gave us the opportunity to establish and improve the delineation of recharge areas. As a result, this book contributes towards a vibrant future for every rural community and assists the nation in framing plans for future development based upon recharge areas.

Tashi Delek!

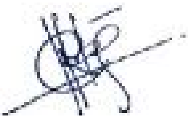
Aum Chime P. Wangdi
Secretary General, Tarayana Foundation

FOREWORD

The book presents maps of potential recharge areas and water quality assessments of critical drying lakes and springs in Southwest Bhutan by integrating hydrogeological fieldwork with community consultation. The study is being conducted in seven districts of Bhutan by the WWF and Tarayana Foundation through an International Climate Initiative (IKI) project from 2020 to 2028, which aims to provide a better understanding and integration of climate-environment risk management.

With the changes in climate and land use, this book comes at a crucial time as the nation faces challenges managing water resources to support sustainable development. Bhutan has been lacking information about groundwater recharge and flow, and this book will hopefully fill that gap. The vulnerability of our water sources is a result of a previous focus on only discharge points and failing to appreciate the importance of recharge areas and total water balances in an area. Among its many benefits, this book will be a great resource for water management in Bhutan, as well as helping to conserve pristine natural resources.

Tashi Delek!



Mr. Vijay Moktan
Conservation Director, WWF Bhutan

PREFACE

Bhutan has experienced a growing water shortage during the past decade as nearby springs, streams, lakes and other water sources have dried up. Climate impact assessments indicated that temperatures in Bhutan will rise, especially in the north. This will lead to a change in precipitation patterns, which will contribute to the drying out of water sources.

During a recent field visit to assess water sources, villagers wanted us to save their water sources by providing funds to fence the water sources off. We tried to tell them that merely protecting the spring would not safeguard water sources from drying in the future. It does not address the problem of where water is entering the ground and how that area is being protected. The first step toward a solution is to clear up this lack of understanding of groundwater.

In the past, the assumption was that water source protection meant physically fencing off or protecting the point where springs discharged. While it is crucial to keep the water collection point clean and free from pathogens, that is not where the problem of water quantity is best addressed. The purpose of this book is to go beyond what has been done to protect water sources and explore the potential recharge zones of drying lakes and springs based on the best science available at the time.

This book on the mapping of recharge areas is ground-breaking and will help our water managers in Bhutan target investments in the right place for the best return on their investment. We have translated the results into plain language with images to assist policymakers who plan development activities. This also addresses water quality and potential changes to water balance, through changes in evapotranspiration, and in this way, we have developed science-based water source management concepts for our region.

It is our hope that the book will be useful to our nation!

Mr. Jambay
Lecturer & Program Leader of Water Resource Management, CNR

ACKNOWLEDGEMENT

It would not have been possible to complete this study without the assistance of Tarayana Foundation and WWF Bhutan, which in turn received funding support from International Climate Initiative, The German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) through the Living Landscapes - Securing High Conservation Values in South-Western Bhutan project.

The authors acknowledge Dr. Carrie E. Jennings, Adjunct Assistant Professor and Research & Policy Director at Freshwater Society, USA, and Mr. Chhimi Dorji Director, Tarayana Centre for Social Research and Development (TCSRD), Tarayana Foundation for editing this work. This book has greatly benefited from the suggestions and comments received on its draft.

The authors would like to extend their gratitude to the staff of the Tarayana Foundation, Ms. Karma Uden, Project Coordinator and Program Officer, as well as Field Officers; Mr. Passang Tobgay, Mr. Jigme Wangchuk, Mr. Namgay, and Mr. Tashi Tshering, and local government officials and staff who assisted with logistics and accompanied during the hydrogeological field survey.

The book was also developed with the technical assistance of Advanced Center for Water Resources Development and Management (ACWADAM), Pune, India; the Watershed Management Division (WMD) under the Department of Forest and Park Services (DoFPS), MoAF; the Freshwater Society, Minnesota, USA; and the International Centre for Integrated Mountain Development (ICIMOD), Nepal. Additionally, we would like to acknowledge and thank the officials of the Department of Forest and Park Services for their assistance during fieldwork.

Thanks also go to Mr. Sonam Moktan, lab technician, Soil, Water and Air Testing lab, College of Natural Resources, as well as community members and field facilitators for answering our interviews and helping to identify the critical drying springs in their communities.

Last but not the least, the authors would like to thank all those who directly and indirectly contributed to the design and creation of this book. The comprehensive efforts of the team are greatly appreciated.

CONTENTS

1. Introduction

It is essential to delineate potential recharge areas for critical water sources in Bhutan in order to prevent further water sources drying up in the region. One of the best ways to adapt to climate change in the region is by engaging in interventions such as the restoration, protection and revival of dying up springs and lakes. It is predicted that climate change will result in high rainfalls within a short timeframe; this rainwater can be harvested on recharge areas through springshed interventions.

In order to ensure water security and resilience within springshed, recharge-area mapping is essential. It is impossible to understand the complete water cycle and, therefore, how water balance changes without identifying the recharge area. For a long time, water managers in our regions have only focused on managing water discharge outlets, not understanding how crucial it is to identify and protect water recharge areas. Traditionally, interventions such as fencing water sources, increasing the size of reservoir tanks, and planting trees around water sources are viewed as ways to protect water resources. However, recent reports of spring water sources and lakes drying up in parts of the country have sparked the desire to think beyond the discharge areas of the water sources. Using this recharge-area mapping, we aim to identify the area through which groundwater enters the soil after snowmelt and rainfall, and consider potential effects to all phases of the water cycle.

As water sources have dried up in some areas of the country, it has been necessary to find alternative water sources. Alternate, newly identified water sources may, however, also dry out with time if they are in the same aquifer. Therefore, it is important to understand the extent of the mountain aquifer feeding the springs and lakes to focus on the right efforts to holistically solve the problem on the ground. To ensure that Bhutan can maintain its critical water sources for the long-term sustainability of the nation, it is important to model and identify which parts of the local water balance have changed so that sound management can be applied.

In the present context, since the recharge areas are unidentified, it is likely that development activities are currently occurring in these areas and destroying or compromising the possibility for water to enter into the ground and hence reducing natural groundwater recharge. As a result of human activities such as the construction of farm roads and buildings that alter the water-bearing geological formation and the construction of impervious surfaces in recharge zones, spring discharge in this aquifer will be reduced. It is also possible that pollutants can enter the ground through unidentified recharge areas.

A study of demarcating recharge areas in the south-western part of Bhutan will help to determine sites for restoring dry up lakes and springs protection through nature-based solutions (NbS) that will increase spring yields, improve water quality, and ensure community security.

Most settlements in Bhutan are located on top of mountains, and therefore they depend on springs that are highly influenced by a complex and poorly defined Himalayan geology. Mountainous areas, where geology is complex, offer many potential paths for water to follow once it enters the ground. Underground geology plays an important role in the movement of water. The presence of springs in mountainous Bhutan is a sign of groundwater, therefore groundwater aquifers are present. However, their precise geometry and extent are difficult to define. As spring water sources are heavily relied upon in Bhutan for domestic and agricultural purposes, introducing interventions to maintain their recharge areas is essential to ensuring water and livelihood security. This book presents recharge areas and a methodology based on an understanding of the slope of local rock units close to the discharge point, which allow us to estimate the extent of the aquifers in mountain-top communities.

2. Controversial role of Forests and Water

In Bhutan, planting trees has been deemed the best way to restore lakes and water sources that are drying up. However, it is important to understand that there is no tree that is capable of manufacturing water. All plants need water to grow and thrive. Planting more trees may mean that more water is being pumped from the ground and transmitted to the atmosphere (evapotranspiration). Although it may fall again locally as precipitation, no water is added to the system. It is also possible for evaporated water to be moved to another area before falling as precipitation. In water-scarce areas, adding water users may not always be appropriate, and at the very least should be investigated with careful measurements of precipitation, evaporation, and evapotranspiration models. Different tree species will have different impacts overall and seasonally, especially if they are deciduous as opposed to those that are evergreen. In other words, planting trees does not affect groundwater recharge directly, but indirectly by providing shade and mulch may increase soil moisture content. Trees themselves need water to conduct soil nutrients through the xylem with the help of water. Adding more trees to a landscape can, therefore, result in more water being lost to the atmosphere.

> "Forests may seasonally dry out the soil which is generally replenished if additional precipitation occurs. However, it is possible for a perpetual soil deficit to be created with negative impacts on recharge to the aquifer. When groundwater is not seasonally recharged, its level may decline, reducing the hydraulic gradient driving water to local discharge areas such as springs and lakes. Thus, the intervention of increasing plant cover regardless of groundwater concerns has become a highly debated topic, especially in areas noted to have drying water sources" (Jambay, 2021).

Planting more trees without knowing forest hydrology and hydrogeology may result in unintended consequences.

Infiltration of water begins in the unsaturated zone (vadose zone) and passes through the saturated zone to recharge the local aquifers, thus increasing the aquifer volume flowing towards the discharge point, such as springs, wetlands, streams, rivers, and lakes. Recharging the actual water table is of prime importance because the communities rely on the springs. It is possible that recharge areas are distant and beyond the control of just one community, so it may be necessary for the communities and dzongkhag officials to cooperate in springshed management.

3. Springshed versus Watershed

The concept of a springshed is slightly different from that of a watershed. A watershed is defined by the surface topography, for example, the ridgeline where all water from the area drains into a common point or common outlet. Whereas, a springshed, may be independent of the surface topography because it is driven by the pressure gradient of rock and sediment plus water pressure. The actual boundary is divided by subsurface phreatic or geological divide. Hence, water from the opposite side of the mountain may be entering a different surface watershed if it is guided by the inclination of the aquifer-forming rocks and driven by the "head" or hydrostatic pressure.

In the watershed concept, two faces of the mountain form two different watersheds but they may be contributing to a single common groundwater discharge point or outlet based on the subsurface divide. Therefore, in this hypothetical case, the whole mountain would be classified under one springshed. Under such circumstances, the runoff calculation for the watershed will be underestimated or overestimated. Also, importantly, recharge areas will fall in another watershed.

In watershed intervention, while taking care of the bigger stream (common outlet), small tributaries and springs which are responsible for forming larger streams dry up. In many cases, the small streams are spring-fed by discrete sources or through baseflow to the streams. In the long run, managers will be able to protect bigger river basins if they address the cause of springs drying up. When the focus is given exclusively to bigger river basins, smaller water spring sources of the first orders may continue to dry up. Thus, springshed management in Bhutan can help focus resources and efforts on the root causes of river flow changes.

4. Groundwater as an Alternative Source of Water

It is crucial for Bhutan to understand the distribution and flow of mountainous groundwater as it begins to extract groundwater. As the flow of water in the mountainous country depends on the geological formation, it is important to understand the primary and secondary geological controls. The exploration and abstraction of groundwater are likely to present an upcoming problem in water resource management because the abstraction of groundwater has begun without a detailed evaluation of the quantity and quality of water available, the transmissivity of particular aquifers, and the specific yield of groundwater. In some communities of Bhutan, groundwater is exploited as an alternative source of drinking water without first determining these parameters, because it might not be sustainable and might affect surface water features, such as springs and lakes, and ecosystems. Abstraction of groundwater without understanding mountain aquifers will lower the regional water table and neighbouring springs will also dry up, thus causing more problems for the local community.

The over-abstraction of groundwater could also pose physical risks. The formation of dolomite and limestone resulted in the formation of karstic caves in Bhutan, such as Gedagom in Thimphu, Rangtse in Haa, and Dawakha in Paro. In such places, borehole drilling may sink entire villages or mountains into caves, similar to what happened in Guatemala City's sinkhole in 2010 (Hermosilla, 2012).

Borewell water in our neighbouring states in India is too salty for human consumption. This is because of an intrusion of seawater from the nearby ocean. The saltwater intrusion from the ocean replaces the freshwater in aquifers. In a mountainous country such as Bhutan, where ocean water is unlikely to enter, sinkholes, which could be potentially deadly, will likely become increasingly common. It is also imperative to understand that groundwater is freshwater and it is generally of good quality.

5. Materials and Methods

Extensive fieldwork was conducted in selected sites covering seven south-western districts of Bhutan namely Chukha, Dagana, Haa, Paro, Thimphu, Tsirang, and Zhemgang (Figure 5.1 and Figure 5.2). The selection of springs and lakes for recharge mapping was done based on the criteria adopted by ICIMOD Manual 2018 (Shrestha, Desai, Mukherji, Dhakal, Kulkarni, Mahamuni, Bhuchar, & Bajracharya, 2018). Local households that used these springs for drinking water were consulted if the availability of the springs changed. Their reports of spring locations and conditions were verified and marked with GPS equipment. The hydrogeological survey featured observations related to the water-bearing potential of different rock types and structural discontinuities such as folds, faults, fractures, and joint patterns as significant factors that may impact how and in what direction water may flow. Using a hand-held Brunton compass, the dip and strike of these structural features were measured.

Bhutan's geology is complex; however, a coarse-resolution geological map (Long, McQuarrie, Tobgay, Grujic, & Hollister, 2011) of the country was used to guide this site-specific investigation. Potential groundwater recharge areas were identified by mapping the water-bearing properties of the rock, as well as their structural characteristics (e.g., fold and fault orientation, dip and strike layers of rock). The hydrogeological layouts of springs in the seven districts were depicted using CorelDraw software to illuminate potential recharge areas for the drying lakes and spring sources.

The water samples were collected from 24 springs, 4 lakes, and 1 stream with the assistance of local guides who were responsible for locating the exact sources of the water. Using the guidelines from the user's manual by Bhushan and Basu (2017), water samples were collected. Water samples were collected manually from streams and lakes by lowering a closed polythene bottle under the surface and closing the cap before lifting it out. Spring samples were taken by cleaning the mouth of the sample bottle and allowing the water to flow into it. The water samples collected were then tightly capped to prevent air interaction (Alam, Hussain, Sultana, and Hasan, Haque, Das, and Mazumder, 2015). The water bottles were properly labelled with the site, date, and time of collection. After being tightly capped, the water samples were taken to a laboratory for analysis.

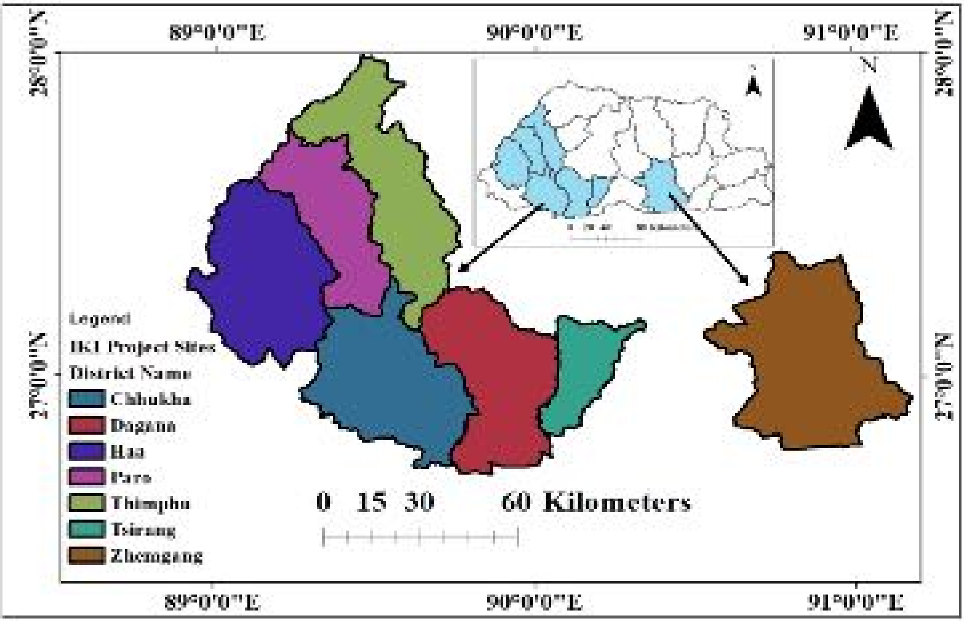


Figure 5.1: Location map of study area

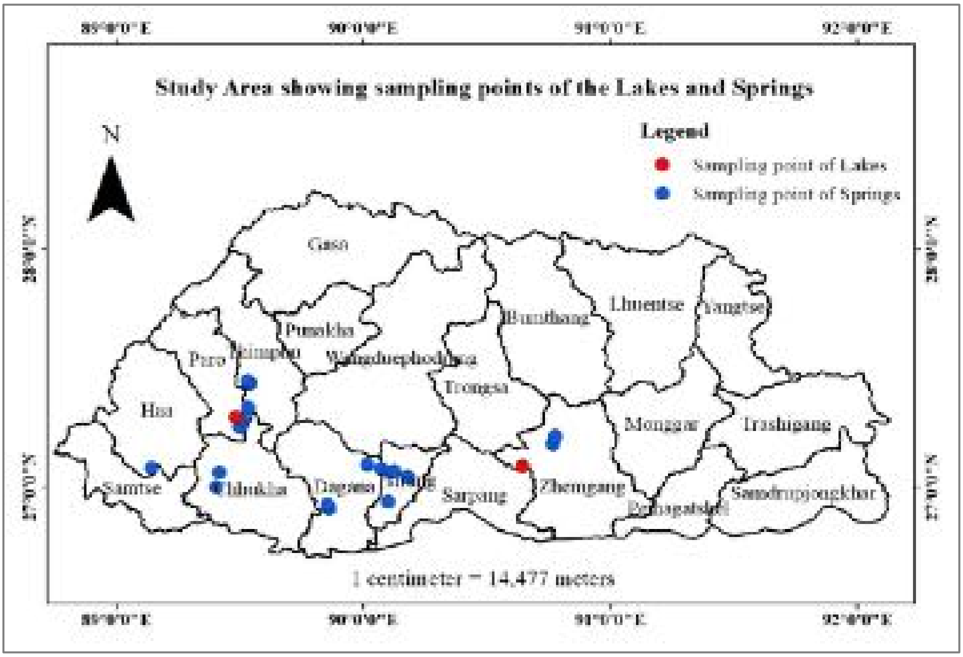


Figure 5.2: Sampling points of the lakes and springs

6. Laboratory Analysis

A water sample was collected in the month of June and July of 2021 from a spot where water naturally flows from the ground. Utilizing the scientific water testing equipment, determinations of Total Dissolved Solids (TDS), pH, water temperature, and salinity were conducted on-site. Other chemical analyses were tested at the Water, Soil, and Air Testing Lab (SWAT) in the College of Natural Resources using standard laboratory manuals. For the purpose of generating precise and accurate results, the following parameters were analysed sequentially: Hardness> Fluoride> Nitrate> Iron> Chlorides> Phosphorous (Jal-TARA, 2020). The parameters of water quality and their descriptive results are summarized in Table 6.2.

7. Results and Discussion

A recharge area is identified to artificially recharge drying aquifers through rainwater harvesting. An intervention such as rainwater harvesting could use the whole mountain slope as a potential harvesting point, by digging contour trenches, pits, bunds, and shallow pits to collect runoff into the recharge area. The current practices of rainwater harvesting from a rooftop is limited by roof area and vessel capacity. Every year, communities can only increase their capacity by adding more harvesting tanks. Springshed management utilizes a rock layer within the mountain as a reservoir, and water can be stored underground. Thus, the reservoir can be almost limitless, and the flow of water will be sustainable year-round.

In order to replenish dry springs, it is necessary to reduce runoff at the surface and enhance infiltration through the ground. The approaches to increasing infiltration in a springshed will differ based on the characteristics of rocks, topography, land-use type, river flows, and land ownership. According to ICIMOD Manual (2018), water infiltration can be encouraged either individually or jointly through structural, vegetative, agronomic, or management measures. The following pages describe the location, the water quality, the geology, and the potential recharge zones for 22 springs and two lakes in seven south-western districts of Bhutan.

Zookpolung spring

Location: Goenpa Maed, Metabkha Gewog, Chhukha
Coordinates: N27º 3' 32.83" E89º 25' 0.37"
Elevation: 1652 m
Discharge: 7.076 lpm (at 3:10 pm, June 24 2021), Volumetic method
Households Dependent: 12
Population Dependent: 140
Status: Dying, Perennial spring

Water Quality - Physical Analysis
pH: 6.24 | **Salinity:** 43.7 ppm | **EC:** 127 µs/cm | **Temperature:** 15.1°C | **TDS:** 92.2 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0.1 mg/l | **Hardness:** 20 mg/l | **Phosphorus:** 0.08 mg/l | **Fluoride:** 0.4 mg/l **Chloride:** 10.635 mg/l

Field Facilitators (from left to right):

Mr. Passang Tobgay (Tarayana)
Mr. Samdrup
Mr. Leki Phuntsho

Figure 1: Zookolung spring

Hydrogeology:

The dominant rocks in the springshed are schist and granite. The schist has preferential layering, is permeable and therefore forms a good aquifer that discharges at the Zookpolung spring. A thin layer of weathered and unconsolidated materials (colluvium) is deposited in the area. The Zookpolung spring emerges from the debris and is thus classified as a depression spring. The granite and schist both dip 30° - 45° towards the southwest. The recharge area for the spring therefore is estimated to lie within a forested area where the schist layer sub-crops beneath thick unconsolidated materials. The proposed protection of this identified recharge area includes the protection from anthropogenic activities and the construction of shallow pits for harvesting rainwater.

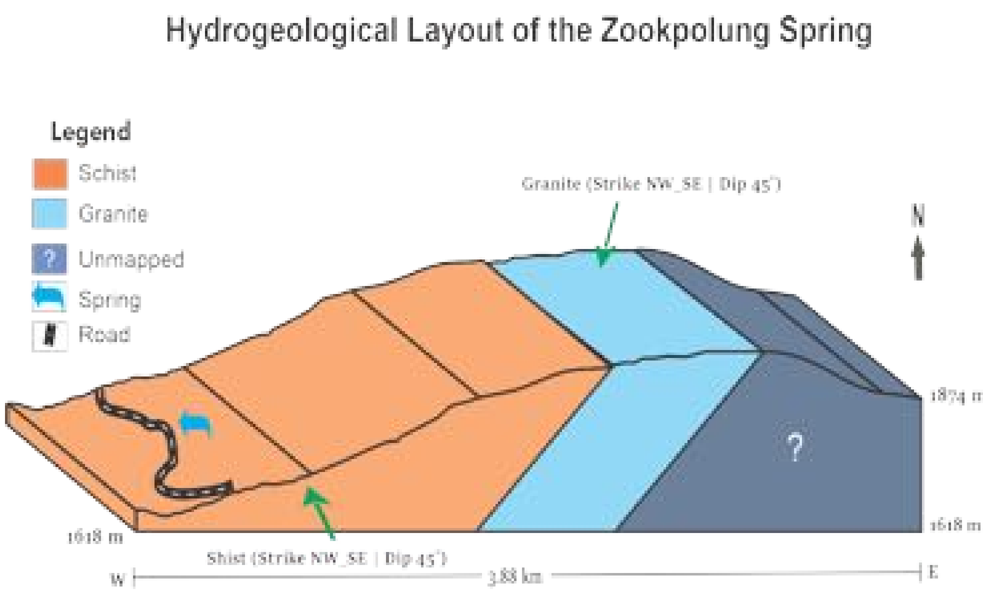


Figure 2: Hydrogeological Layout the of the Zookpolung spring

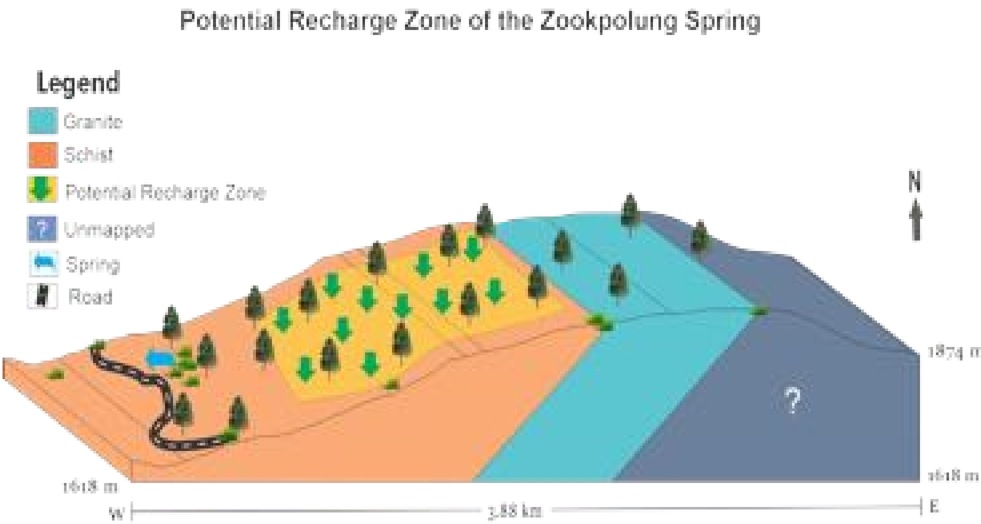


Figure 3: Potential Recharge Zone of the Zookpolung spring

Figure 4: Measuring spring discharge

Figure 5: Lithology of Zookpolung spring

Figure 6: Location of the recharge area and Zookpolung spring on the Google Earth image.

Darpani spring

Location: Damchekha, Logchina Gewog, Chukha
Coordinates: N26º 59' 54.64" E89º 24' 13.32"
Elevation: 1426 m
Discharge: 1.58 lpm (at 10 am, June 26, 2021), Volumetric method
Households Dependent: 40
Population Dependent: 310
Status: Dying, Perennial spring

Water Quality - Physical Analysis
pH: 7.6 | **Salinity:** 21.4 ppm | **EC:** 68 µs/cm | **Temperature:** 15.6°C | **TDS:** 37.8 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 40 mg/l | **Phosphorus:** 0.1 mg/l | **Fluoride:** 0.6 mg/l | **Chloride:** 0 mg/l

Field Facilitators
(from left to right):

Mr. Rajmaan Rai
Mr. Passang Tobgay
(Tarayana)

Figure 1: Darpani spring

Hydrogeology:

This springshed contains granitic gneiss underlain by schist. As granite is less permeable, it forms an aquitard, which discharges water at the point of contact with the granite and a blanket of loose debris that surrounds it, feeding the Darpani spring. The slopes have shed weathered rock creating a blanket of unconsolidated materials or colluvium comprised of granite and schist fragments with a wide range of grainsize ranging from fines to even pebbles in the places. This colluvial debris acts as the main aquifer for the Darpani spring. The spring that emerges from the debris is in contact with granite and is therefore classified as depression Springs. The area on the south-east (SE) slope above the spring is the recharge area for the spring. The population dependency of this particular springshed is 310, making it an excellent target for springshed intervention.

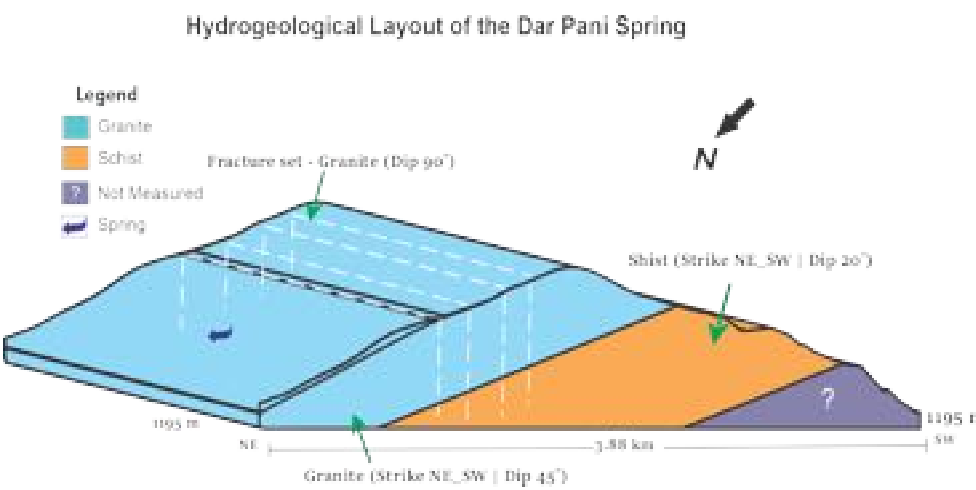


Figure 2: Hydrogeological Layout the of the Darpani spring

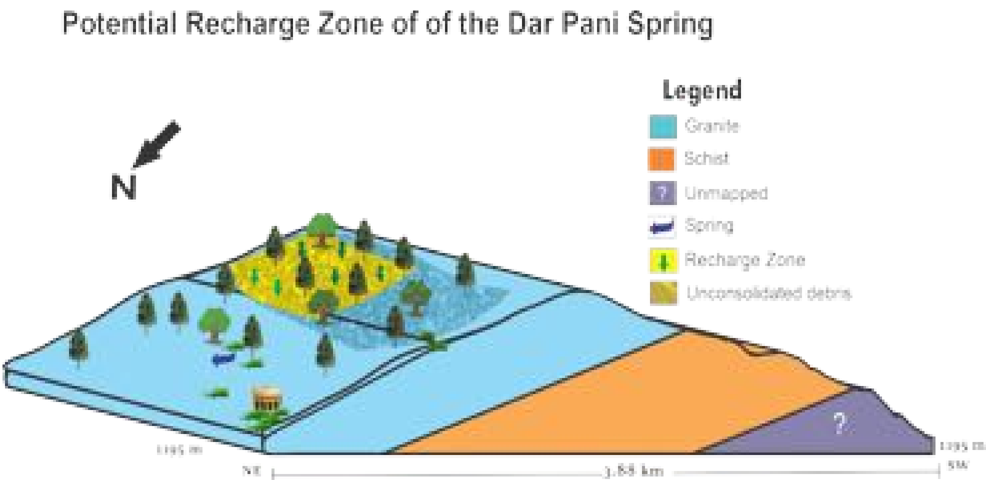


Figure 3: Potential Recharge Zone of the Darpani spring

Figure 4: Measuring of spring water quality

Figure 5: Measuring dip and strike of the rocks

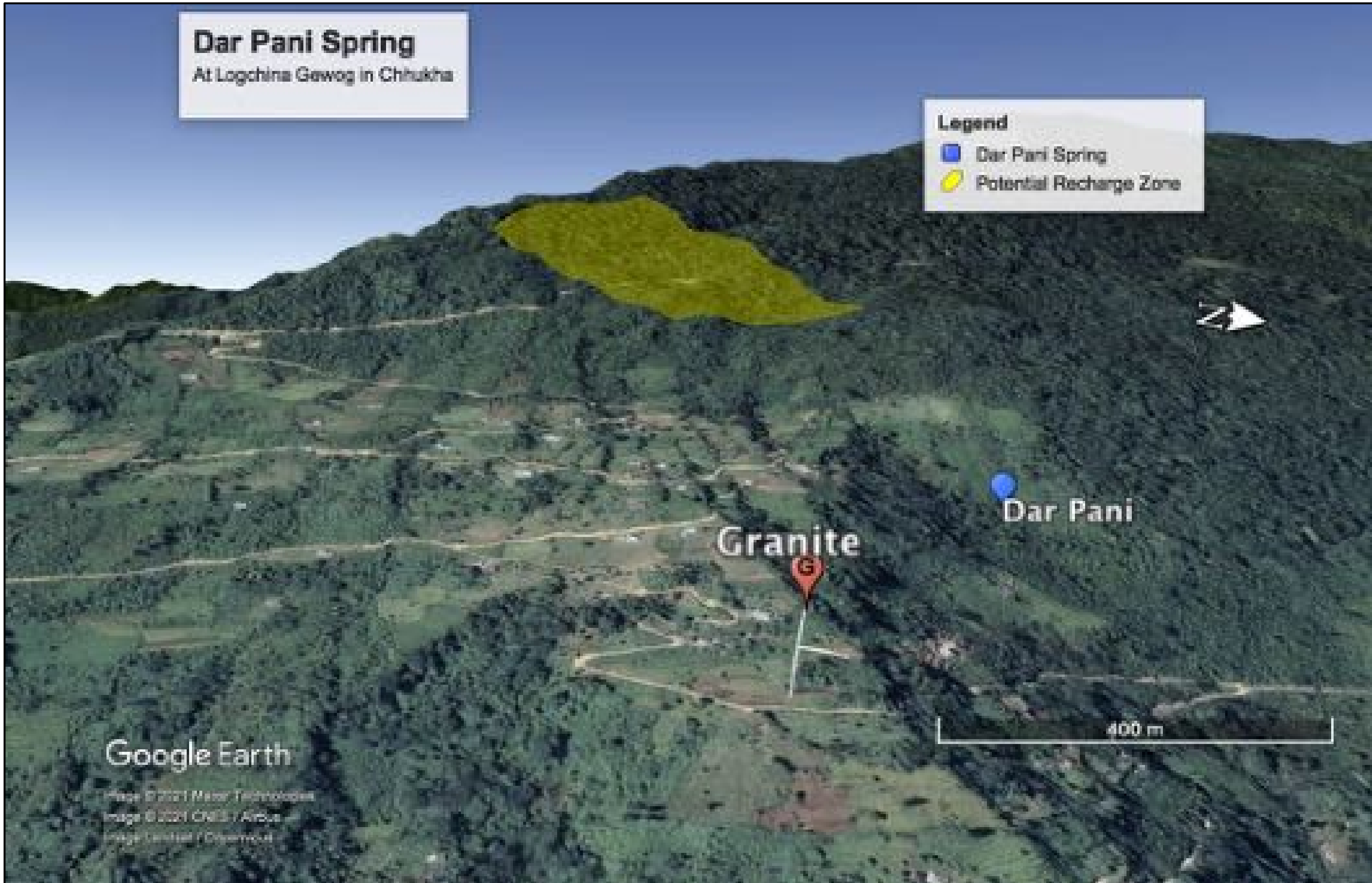


Figure 6: Location of the recharge area and Dar Pani spring on the Google Earth image.

Larjab Renewable Natural Resources (RNR) spring source

Location: Phuentshogang, Bana, Larjab Gewog, Dagana
Coordinates: N 27º 5' 28.54" E 90º 0' 49.28"
Elevation: 1671 m
Discharge: 2.448 lpm (at 11:35 pm, July 5, 2021), Volumetric method
Household Dependent: 8
Population Dependent: 20
Status: Dying, Perennial spring

Water Quality - Physical Analysis
pH: 6 | **Salinity:** 31 ppm | **EC:** 88 µs/cm | **Temperature:** 15°C | **TDS:** 63 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 56 mg/l | **Phosphorus:** 0.1 mg/l | **Fluoride:** 0.7 mg/l | **Chloride:** 0 mg/l

Field Facilitators (from left to right):

Mr. Pema Jamtsho (Gewog Adm. Officer)
Mr. Jigme Wangchuk (Tarayana)

Figure 1: Larjab RNR spring source

Hydrogeology:

This springshed is comprised of sandstone with a thin layer of schist overlying it. The sandstone is exposed at the base of Larjab RNR spring source and the spring originates from sandstone below the schist layer. Although locally the rocks dip towards the northeast away from spring, however, two sets of fractures guide the water towards the Larjab RNR spring source. This spring is classified as a depression spring. The forested area on the ridge of sandstone forms the recharge area of the Larjab RNR spring source.

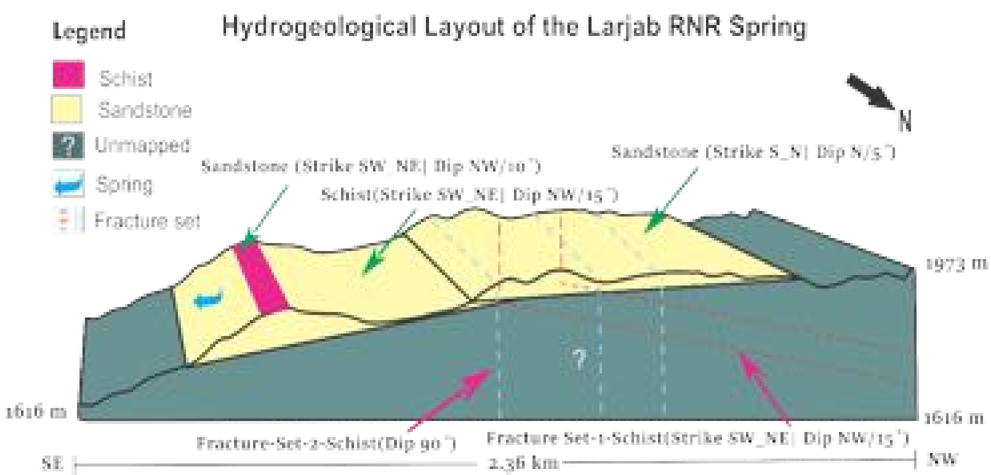


Figure 2: Hydrogeological Layout the of Larjab RNR spring source

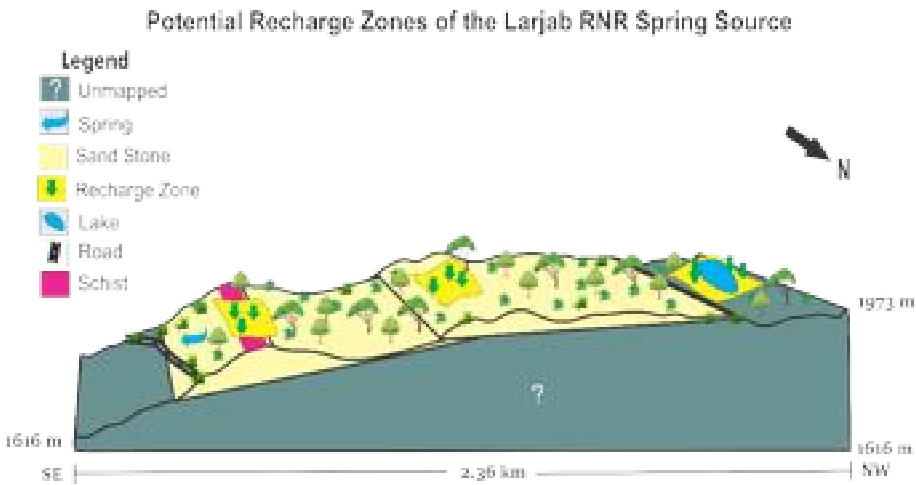


Figure 3: Potential Recharge Zone of the Larjab RNR spring

Figure 4: Lithology of Larjab

Figure 5: Measuring spring water quality

Figure 6: Location of the recharge area and Larjab RNR spring on the Google Earth image.

Larjab Tsho (Lake)

Location: Atsephu, Bana, Larjab Gewog, Dagana
Coordinates: N 27º 5' 28.54" E 90º 0' 49.28"
Elevation: 1671 m
Population Dependent: For animals
Status: Dying ,Perennial

Water Quality - Physical Analysis
pH: 6.7 | **Salinity:** 33.3 ppm | **EC:** 96.8 µs/cm | **Temperature:** 16.4°C | **TDS:** 68 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 3 mg/l | **Hardness:** 720 mg/l | **Phosphorus:** 1 mg/l | **Fluoride:** 1.2 mg/l | **Chloride:** 0 mg/l

Field Facilitators
(From left to right):

Mr. Jigme Wangchuk (Tarayana)
Mr. Bal Brd.
Mr. Pema Jamtsho (Gewog Adm. Officer)

Figure 1: Larjab Tsho (Lake)

Shachena Chhu spring

Location: Thasa Zampa, Thasa, Larjab Gewog, Dagana
Coordinates: N 27º 4' 27.84" E 90º 4' 12.47"
Elevation: 548 m
Discharge: Almost Driedup, in drops (July 14, 2021), Volumetric method
Household Denependent: 2
Population Dependent: 6
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.71 | **Salinity:** 109 ppm | **EC:** 340 µs/cm| **Temperature:** 22°C |
TDS: 235 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 1 mg/l | **Hardness:** 56 mg/l | **Phosphorus:** 0.2 mg/l |
Fluoride: 1.5 mg/l | **Chloride:** 10.635 mg/l

Figure 1: Shachena Chhu spring

Field Facilitators:

Mrs. Pema Lhamo
(Water user)
Mr. Jigme Wangchuk
(Tarayana)

Hydrogeology:

Shachena Chhu spring emerges on the southeast slope of the mountain ridge. The entire ridge is comprised of schist. The multiple fractures in the schist dip 15° towards the southeast and are highly weathered in places. The multi-structural geological formations are observed just above the dying spring. At the same elevation there is another spring for animal drinking that is aligned with a fracture set (dip 65° towards the northeast). Therefore, these springs are classified as fracture springs. There is thick debris along the fracture plane that conveys the water to the spring. This also indicates that the spring is a combination of depression and contact type. The recharge areas for this spring follow the orientation of the fracture sets towards the dried-up Thasa lake on top of the ridge toward the southwest.

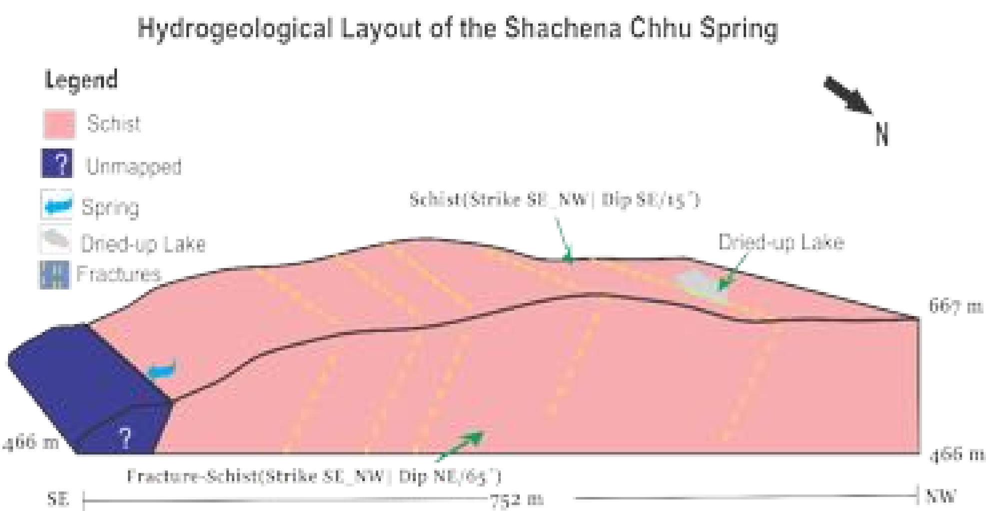


Figure 2: Hydrogeological Layout the of the Shachena Chhu spring

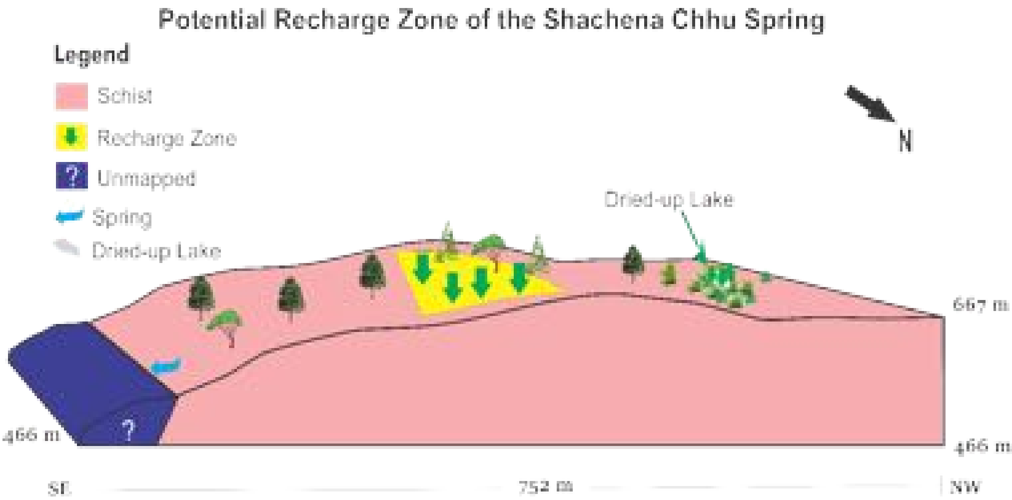


Figure 3: Potential Recharge Zone of the Shachena Chhu spring

Figure 4: Collecting spring water sample

Figure 5: Spring source for livestock drinking

Figure 6: Location of the recharge area and Shachena Chhu spring on the Google Earth image.

Thasa Tsho (lake)

Location: Thasa, Larjab Gewog, Dagana
Coordinates: N 27º 4' 37.81" E 90º 4' 1.42"
Elevation: 627m
Population Dependent: For animals
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.72 | **Salinity:** 82.9 ppm | **EC:** 248 µs/cm | **Temperature:** 29°C | **TDS:** 176 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0.7 mg/l | **Hardness:** 48 mg/l | **Phosphorus:** 0.7 mg/l | **Fluoride:** 0.6 mg/l | **Chloride:** 38.995mg/l

Field Facilitators:

Mrs. Tegomo, (Tshopa)
Mr. Jigme Wangchuk (Tarayana)

Figure 1: Thasa Tsho (lake)

Devi Thang spring

Location: Devi Thang, Nimtola, Dorona Gewog, Dagana
Coordinates: N 26º 54' 20.52"E 89º 51' 34.67"
Elevation: 1306 m
Discharge: 0.639 lpm (at 12.20 pm, July 7, 2021),Volumetric method
Household Dependent: 19
Population Dependent: 40
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.1 | **Salinity:** 17.6 ppm | **EC:** 39 µs/cm | **Temperature:** 17°C | **TDS:** 27 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 20 mg/l | **Phosphorus:** 0.1 mg/l | **Fluoride:** 0.6 mg/l | **Chloride:** 0 mg/l

Field Facilitators (from left to right):

Mr. Pema Tobten (Tshokpa)
Mr. Jigme Wangchuk (Tarayana)

Figure 1: Devi Thang spring

Hydrogeology:

The entire springshed of Devi Thang spring is comprised of schist. The schistosity dips 5° towards the northeast and has parallel vertical fractures. Devi Thang spring emerges on the north-eastern slope of the mountain from beneath thick unconsolidated debris. The spring is classified as a depression spring and the location of the recharge area of the aquifer is above the spring along Gewog Center Road. Therefore, rainwater runoff from the road should be directed to the aquifer for recharging the dying Devi Thang spring at Nimtola, Dorona Gewog, Dagana.

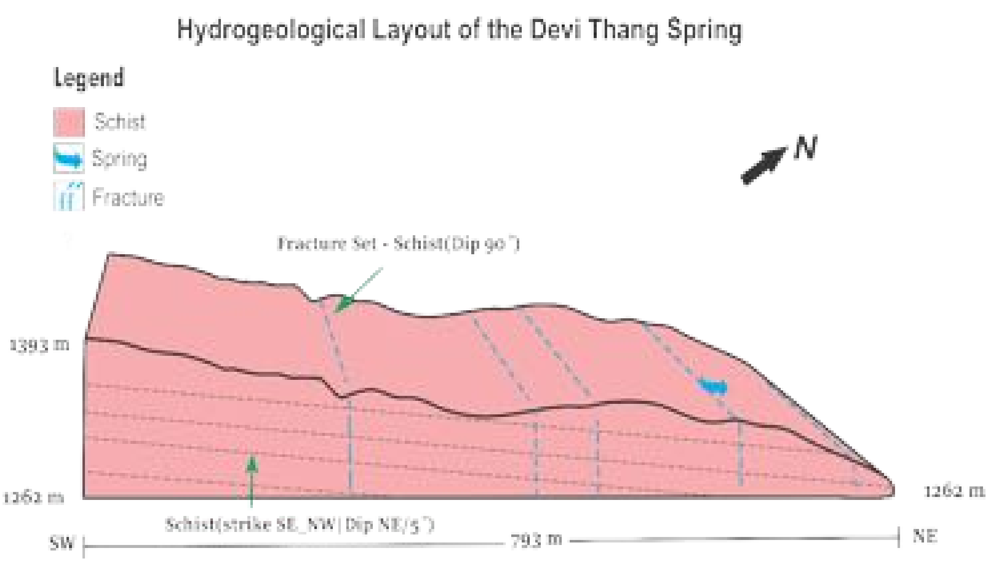


Figure 2: Hydrogeological Layout the of the Devi Thang spring

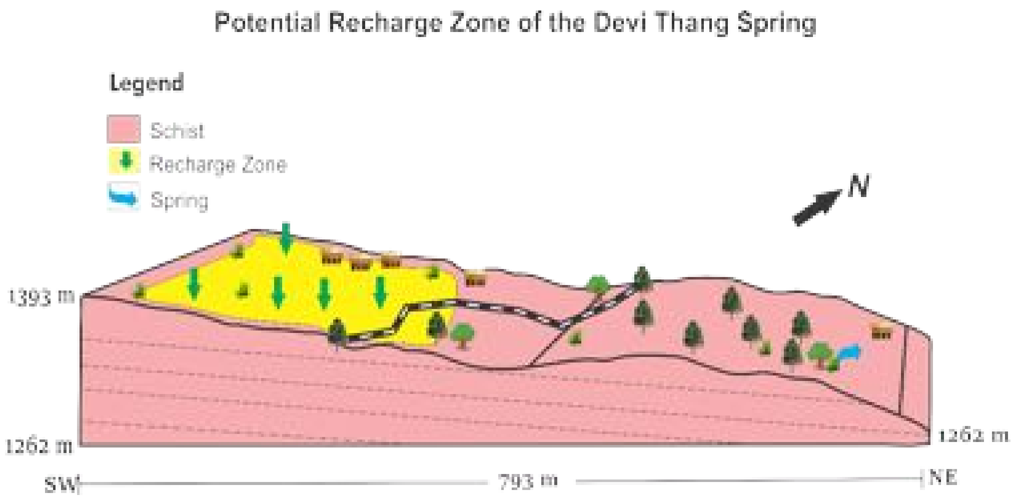


Figure 3: Potential Recharge Zone of the Devi Thang spring

Figure 4: Fracture spring source in nearby aquifer

Figure 5: Lithology of Nimtola

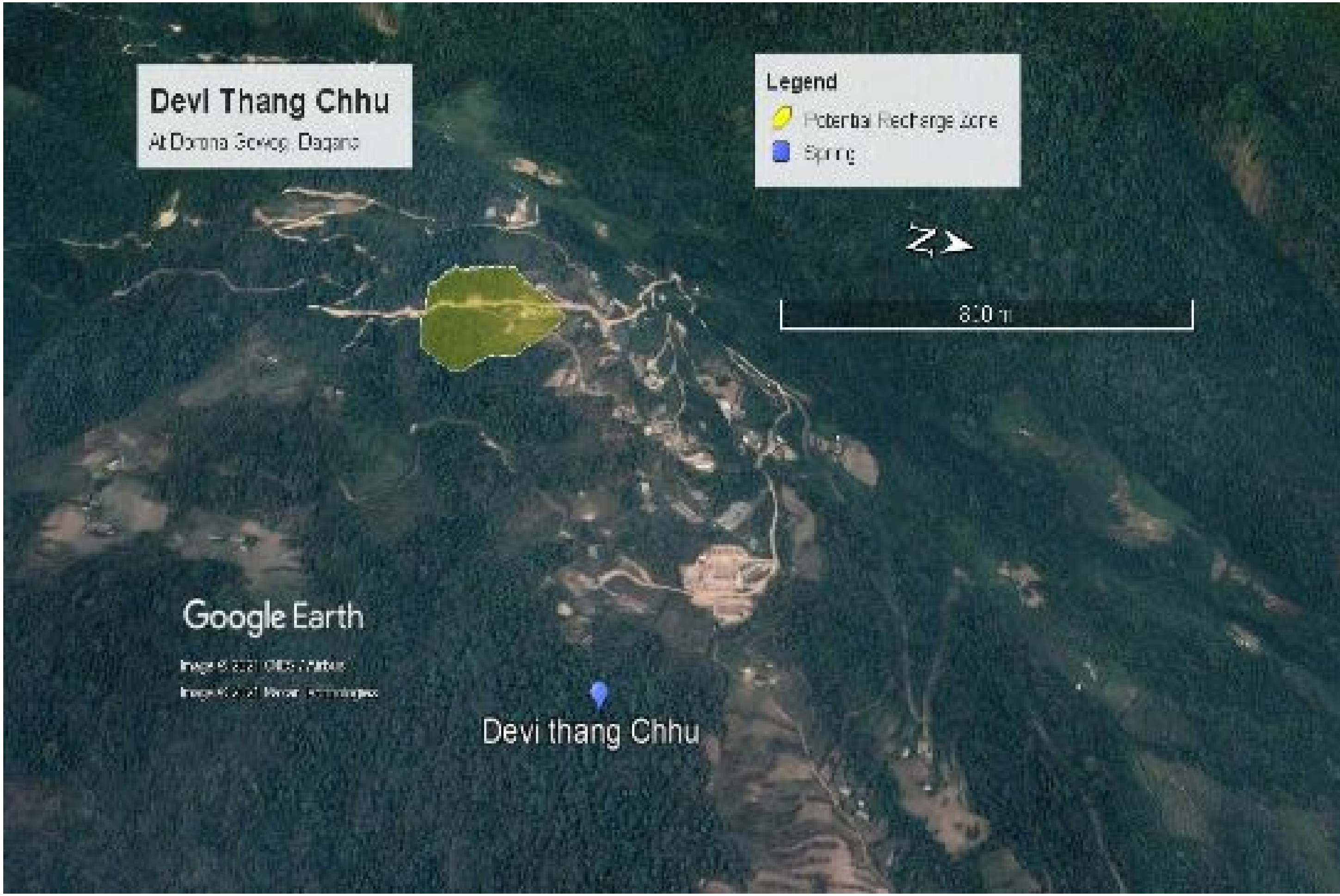


Figure 6: Location of the recharge area and Devi Thang spring on the Google Earth image.

Mamethang spring

Location: Mamethang, Dorona Gewog, Dagana
Coordinates: N 26º 55' 46.31"E 89º 51' 1.48"
Elevation: 1620 m
Discharge: 4.12 lpm (at 5.40 pm, July 7, 2021), Volumetric method
Household Dependent: 4
Population Dependent: 14
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.17| **Salinity:** 16.5 ppm | **EC:** 35.5 µs/cm | **Temperature:** 15°C | **TDS:** 26.4 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 360mg/l | **Phosphorus:** 0.4 mg/l | **Fluoride:** 0.7 mg/l | **Chloride:** 0 mg/l

Field Facilitators (from left to right):

Mr. Karma Tashi (Water user)
Mr. Jigme Wangchuk (Tarayana)

Figure 1: Mamethang spring

Pep Chhu spring

Location: Yokha, Rangtse, Gakiling Gewog, Haa
Coordinates: N 27º 4' 40.76" E 89º 8' 27.28"
Elevation: 1688 m
Discharge: 2.8838 lpm (at 10.40 am, June 26, 2021)
Household Dependent: 66
Population Dependent: 350
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.7 | **Salinity:** 95.5 ppm | **EC:** 302 µs/cm | **Temperature:** 15.1°C | **TDS:** 215 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 240 mg/l | **Phosphorus:** 0.3 mg/l | **Fluoride:** 0.8 mg/l | **Chloride:** 38.995 mg/l

Field Facilitators (from left to right):

Mr. Sangay Tempa
Mr. Tashi Tshering (Tarayana)
Mr. Jambay (Expert)

Figure 1: Pep Chhu spring

Hydrogeology:

Pep Chhu spring originates in an area beneath agricultural land. Schistose is sporadically exposed at the surface, dips 10° to the north, and is highly weathered. The spring is surrounded by a thick layer of debris and shrubs. This spring is categorized as a depression spring. This spring is fenced but the area where it recharges is not. Local facilitators report that this springshed experiences a high amount of rainfall, and that the spring dependency population is relatively high among other sources of water; therefore, focusing interventions on this spring has the potential to generate considerable benefit for the communities.

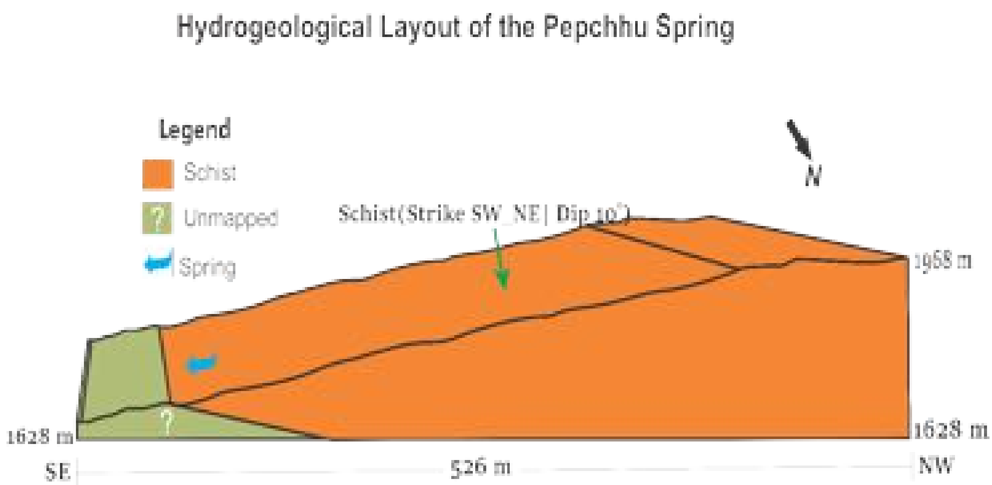


Figure 2: Hydrogeological Layout the of the Pep Chhu spring

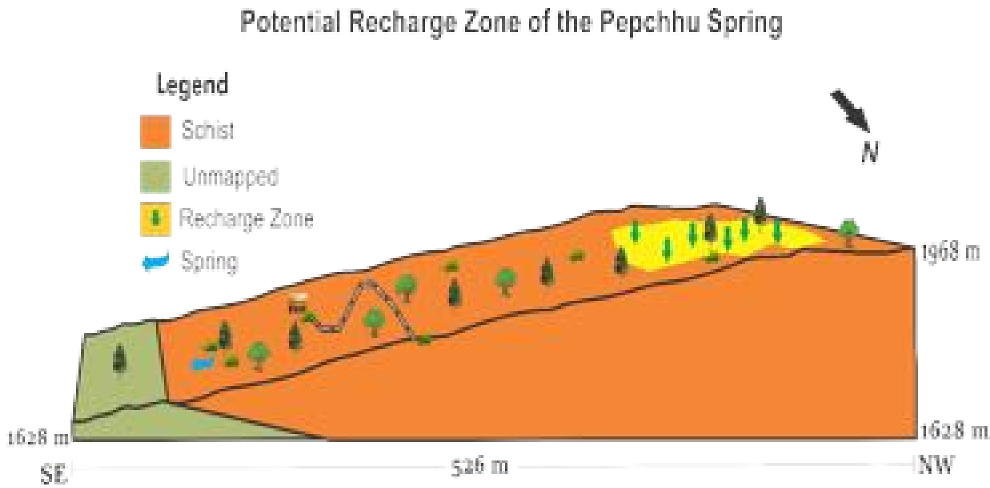


Figure 3: Potential Recharge Zone of the Pep Chhu spring

Figure 4: Measuring dip and strike of rocks

Figure 5: Lithology of Rangtse

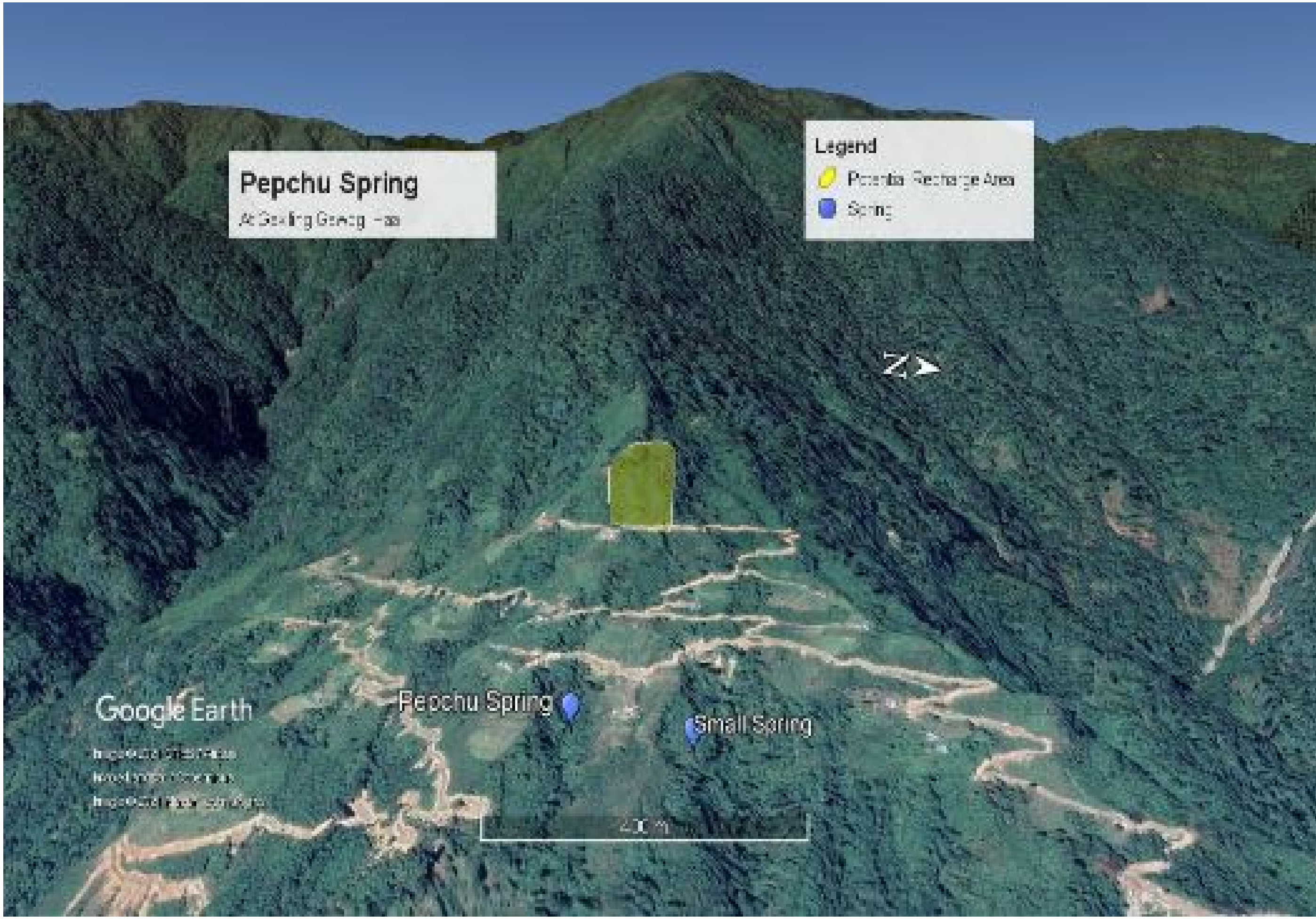


Figure 6: Location of the recharge area and Pep Chhu spring on the Google Earth image.

Sanglungpa A spring

Location: Sali, Dogar Gewog, Paro
Coordinates: N 27º 15' 0.9" E 89º 30' 3.53"
Elevation: 2595 m
Discharge: 2.24 lpm (at 12:22 pm, June 27, 2021), Volumetric method
Household Dependent: 45
Population Dependent: 141
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.7| **Salinity:** 102 ppm | **EC:** 334 µs/cm | **Temperature:** 10°C |
TDS: 237 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0.2 mg/l | **Hardness:** 160 mg/l | **Phosphorus:** 0.1 mg/l |
Fluoride: 0.7 mg/l | **Chloride:** 10.63 mg/l

Field Facilitators:

Mr. Rinzin (Tshokpa)
Mr. Jamyang Zangpo (DoFPs)
Mr. Passang Tobgay (Tarayana)

Figure 1: Sanglungpa A Spring

Hydrogeology:

This springshed is made up of schist at the top and granite at the lower valley. The permeable schist acts as a water-holding mass for recharging both springs: Sanglungpa A and Sanglungpa B. The layers of schist and granite dip 10° to the southeast and the springs emerge just above a granite layer which is impermeable. Therefore, these two springs share a common aquifer. The recharge area is located towards the southwest and recharging this area ensures recharging of both springs. Currently, debris and *Salix* sp lie above springs, therefore, these springs can be

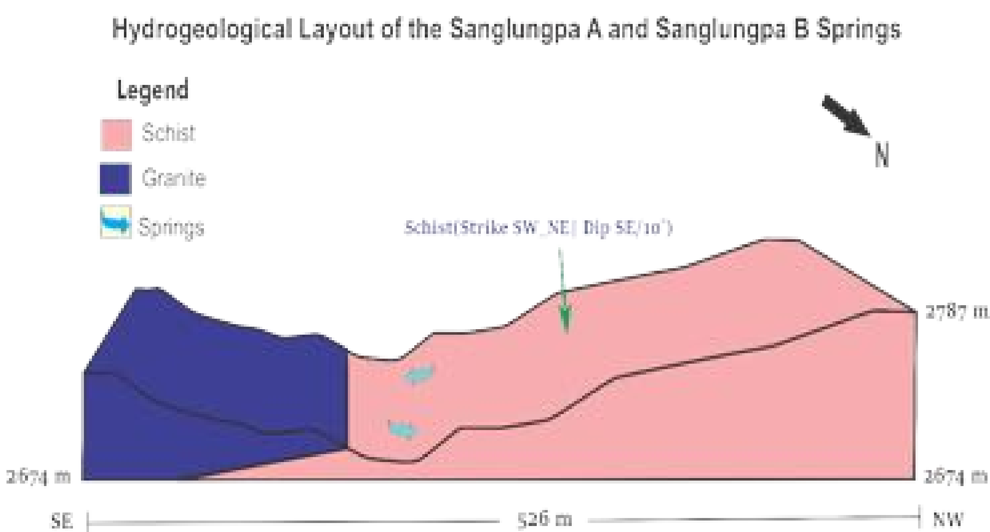


Figure 2: Hydrogeological Layout of the Sanglungpa A and Sanglungpa B springs

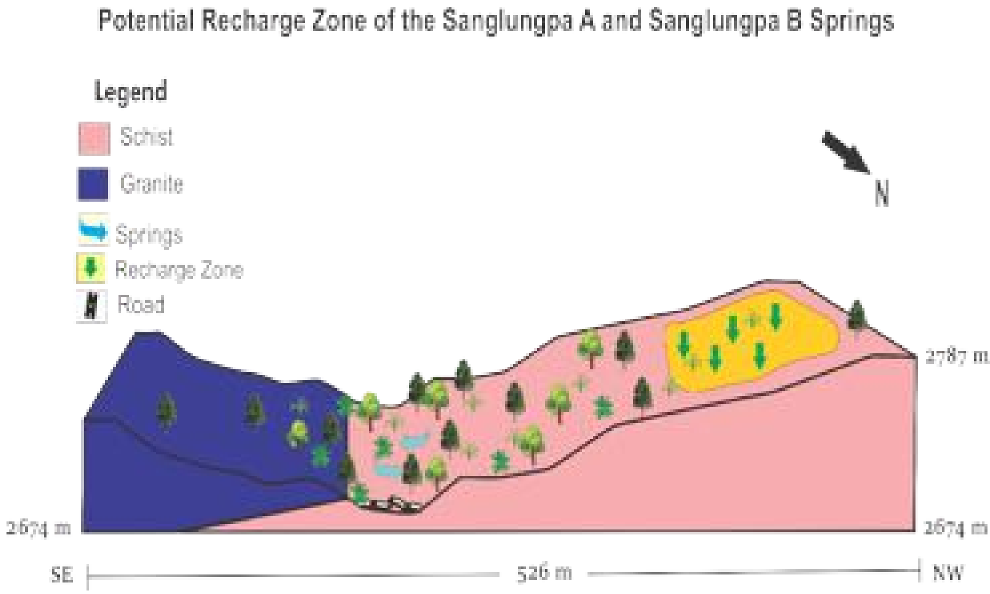


Figure 3: Potential Recharge Zone of the Sanglungpa A and Sanglungpa B springs

Figure 4: Measuring of spring discharge

Figure 5: Collecting spring water sample

Figure 6: Location of the recharge area and Sanglungpa A and Sanglungpa B springs on the Google Earth image.

Sanglungpa B spring

Location: Sali, Dogar Gewog, Paro
Coordinates: N 27º 15' 1.55" E 89º 29' 59.75"
Elevation: 2687 m
Discharge: 3.41 lpm (at 1:08 pm, June 27, 2021),Volumetric method
Household Dependent: 11
Population Dependent: 55
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 8.2| **Salinity:** 118 ppm | **EC:** 381 µs/cm | **Temperature:** 11.1°C |
TDS: 270 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 160 mg/l | **Phosphorus:** 0.2 mg/l |
Fluoride: 0.7 mg/l | **Chloride:** 81.535 mg/l

Field Facilitators

Mr. Rinzin
(Tshokpa)
Mr. Passang Tobgay
(Tarayana)

Figure 1: Sanglungpa B Spring

Meni Menchu spring

Location: Dawakha, Dogar Gewog, Paro
Coordinates: N 27º 17' 0.89" E 89º 30' 51.73"
Elevation: 2559 m
Discharge: 0.0962 lpm (at 4.04 pm, June 27, 2021), Volumetric method
Household Dependent: 30
Population Dependent: 150
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.725| **Salinity:** 239 ppm | **EC:** 649.2 µs/cm | **Temperature:** 12.1°C | **TDS:** 534 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0.1 mg/l | **Hardness:** 267 mg/l | **Phosphorus:** 0.08 mg/l | **Fluoride:** 0.8 mg/l | **Chloride:** 31.905 mg/l

Figure 1: Meni Menchu spring

Hydrogeology:

This springshed is made up of unconsolidated debris or colluvium, the size of which ranges from small particles to boulders of schist and granite. The spring originates at a point where there is a change in slope and is thus classified as a depression spring. Proposed work for the recharge of spring: the catchment of the spring falls below the impermeable granite layer on the schist which is covered by sparse *Pinus* sp. Therefore, the percolation pits and staggered contour trenches in this area will be ideal for the recharge of the spring.

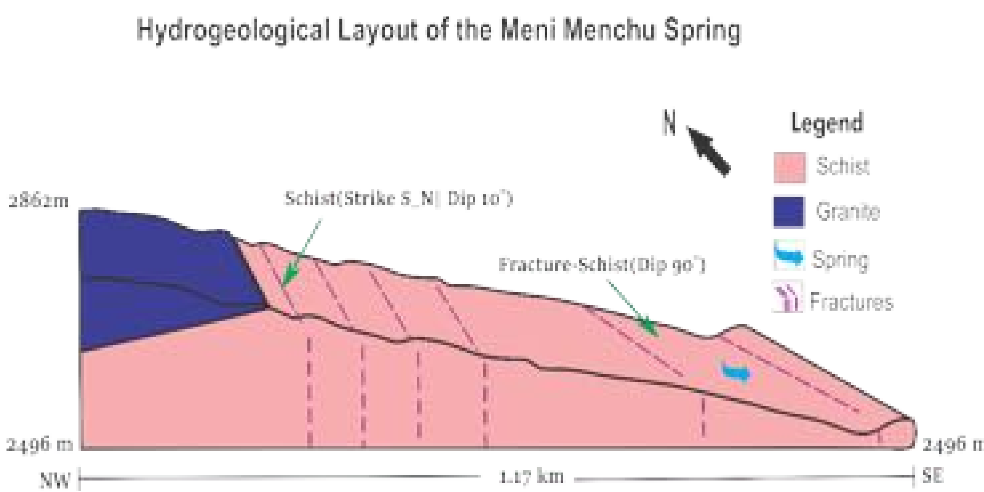


Figure 2: Hydrogeological Layout the of the Meni Menchu spring

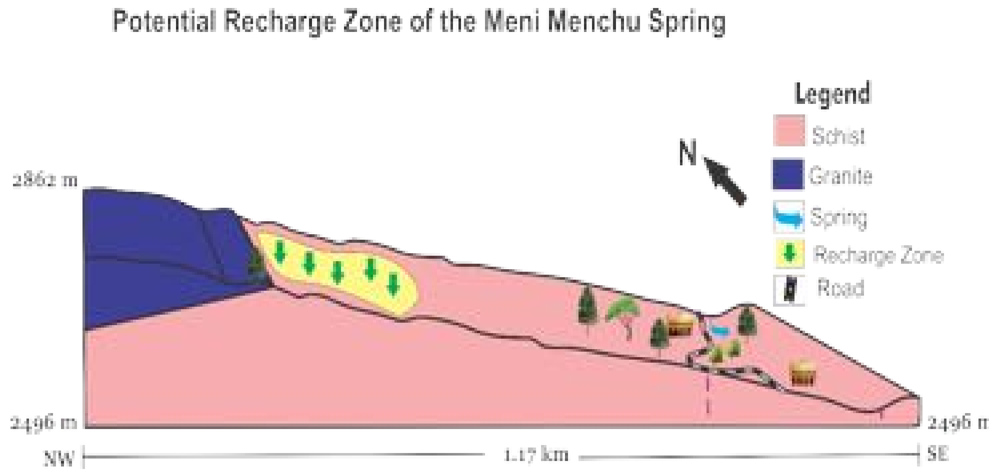


Figure 3: Potential Recharge Zone of the Meni Menchu spring

Figure 4: Measuring of spring discharge

Figure 5: Collecting spring water sample

Figure 6: Location of the recharge area and Meni Menchu spring on the Google Earth image.

Laynatsho (lake)

Location: Tsho Re Mo, Dawakha, Dogar Gewog, Paro
Coordinates: N 27º 17' 33" E 89º 29' 5"
Elevation: 3580 m
Population Dependent: For Animals
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.92| **Salinity:** 25.1 ppm | **EC:** 71.3 µs/cm| **Temperature:** 13.17°C | **TDS:** 50.8 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 2.5 mg/l | **Hardness:** 1200 mg/l | **Phosphorus:** 0.4 mg/l | **Fluoride:** 1.5 mg/l | **Chloride:** 0 mg/l

Figure 1: Laynatsho (lake)

Hydrogeology:

The entire catchment around Laynatsho Lake is made up of schist. The schists dip 15°-25° towards the northeast. Farther away, there are small areas of granite dipping 15°northeast

Recommendations:

- Dig shallow pits at different locations within the catchment of the lake.
- Install monitoring equipment to measure water level in the lake over time to understand the relationship between precipitation and lake level and if there is a significant lag time.

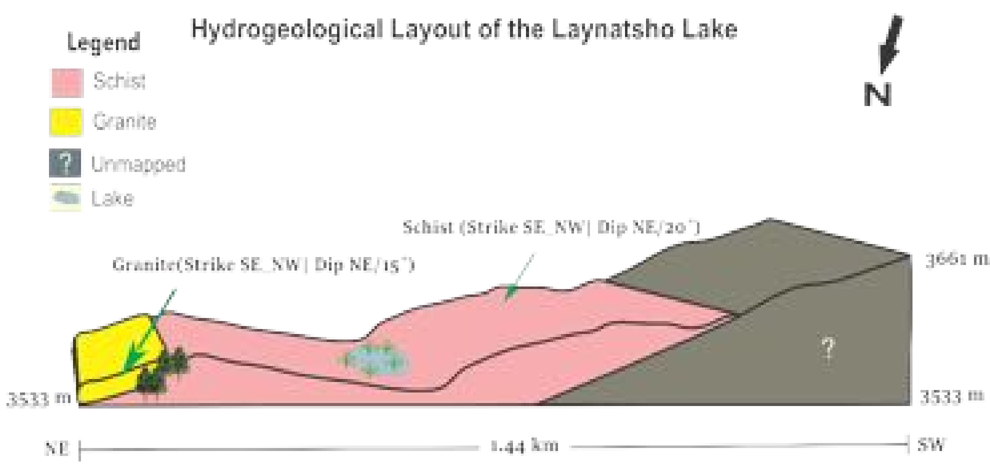


Figure 2: Hydrogeological Layout the of the Laynatsho lake

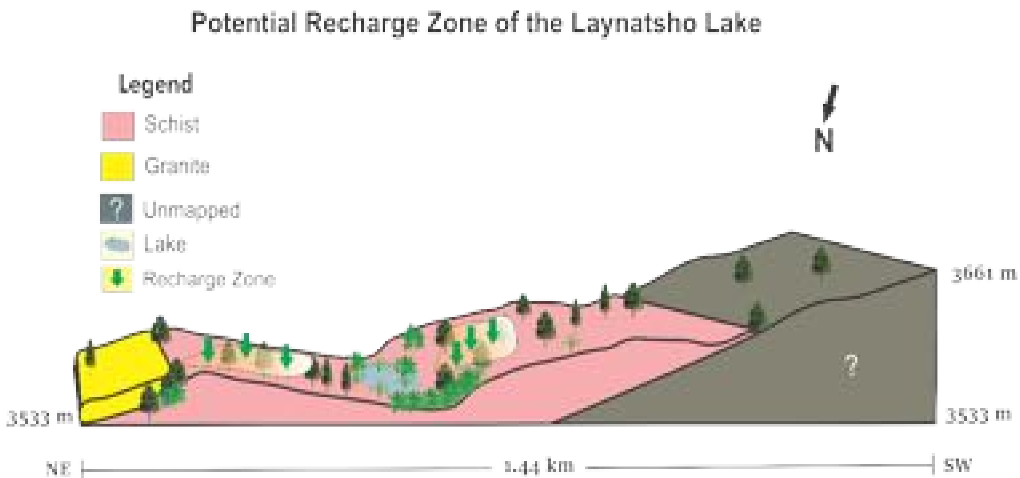


Figure 3: Potential Recharge Zone of the Laynatsho Lake

Figure 4: Measuring depth of Lake

Figure 5: Wetlands at the Laynatsho Lake

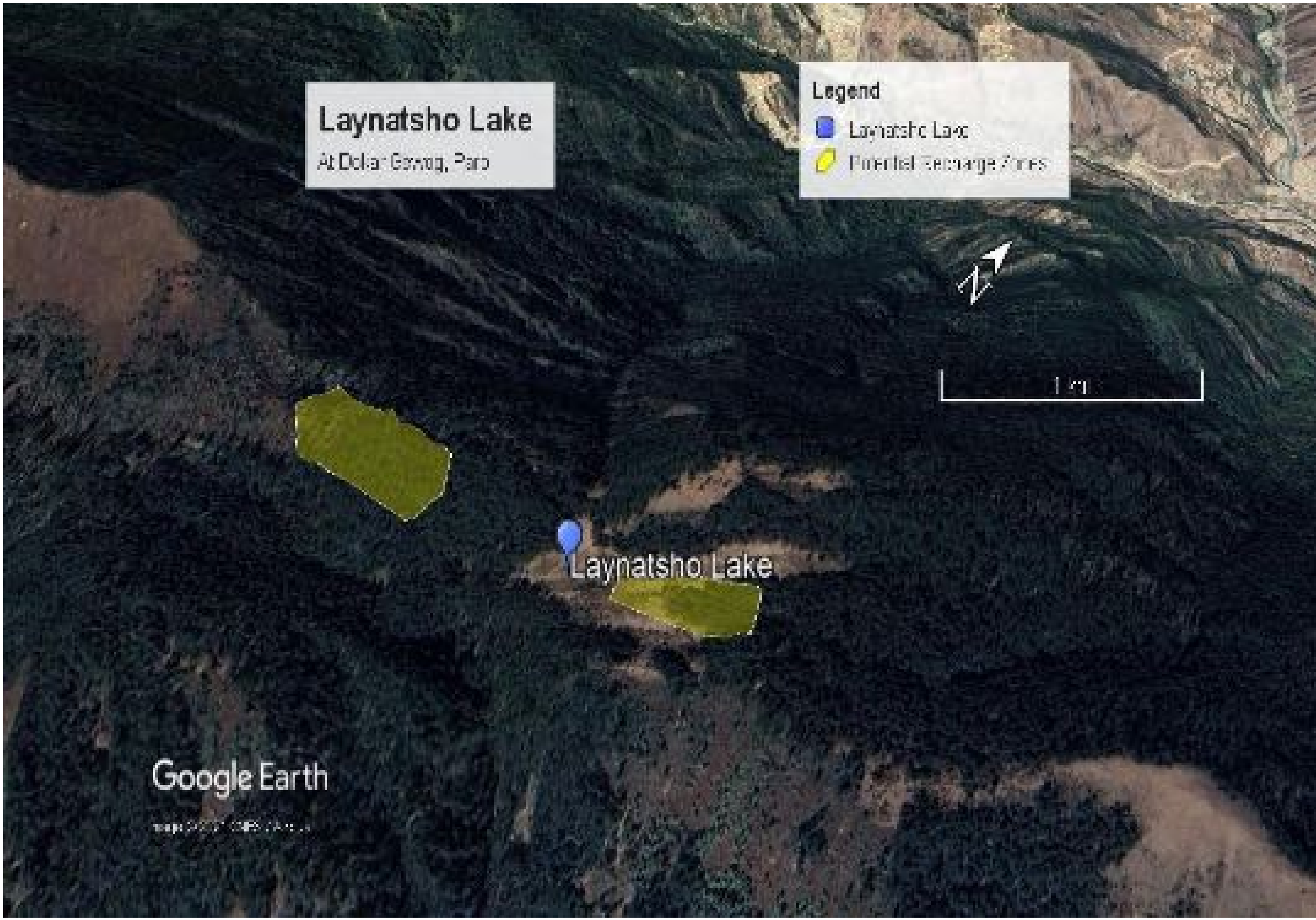


Figure 6: Location of the recharge area and Laynatsho Lake on the Google Earth image.

Zaka spring

Location: Tsephu, Dogar Gewog, Paro
Coordinates: N 27º 20' 9.28" E 89º 31' 51.96"
Elevation: 2571 m
Discharge: 0.0409 lpm (at 6.52 pm, June 27, 2021), Volumetric method
Population Dependent: 40
Status: No Change

Water Quality - Physical Analysis
pH: 7.71| **Salinity:** 129 ppm | **EC:** 411 µs/cm | **Temperature:** 13.9°C | **TDS:** 290 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 200 mg/l **Phosphorus:** 0.2 mg/l | **Fluoride:** 0.7 mg/l | **Chloride:** 35.45 mg/l

Field Facilitators (From left to right):

Mr. Gyem Rinzin (Tshokpa)
Mr. Passang Tobgay (Tarayana)

Figure 1: Zaka Spring

Hydrogeology:

The entire Zaka springshed is comprised of schist. The schist dips 10° towards the southwest. The recharge area falls within the grassland and the Zaka spring emerges in a depression point. This spring is classified as a depression spring. This spring has a better chance of revival as the area is covered by grassland but the area receives sparse rainfall. Abstracting water through borehole installation would further compromise this spring.

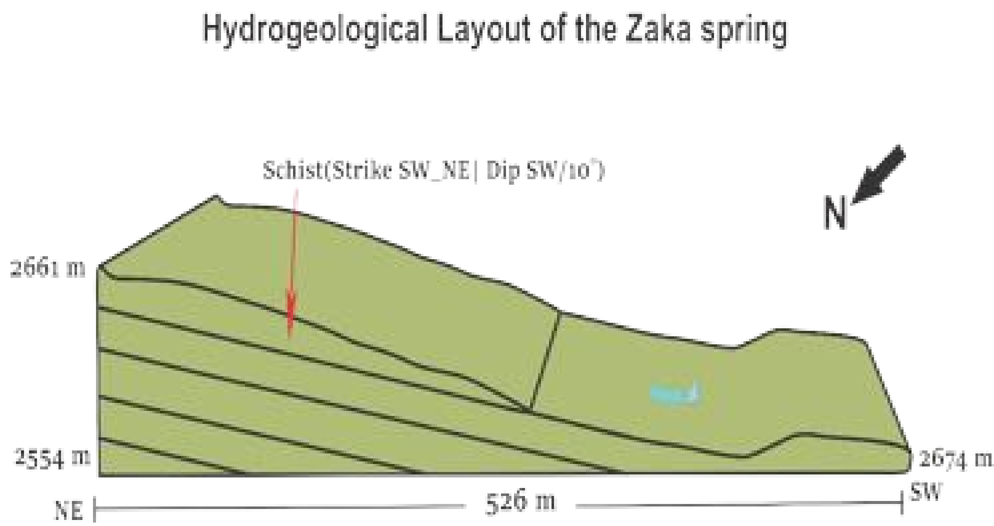


Figure 2: Hydrogeological Layout the of Zaka spring

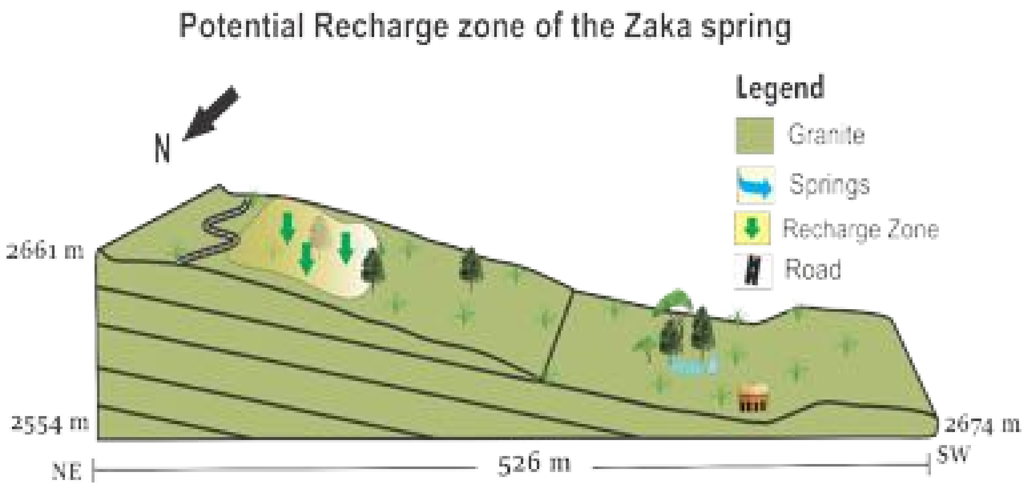


Figure 3: Potential Recharge Zone of the Zaka spring

Figure 4: Measuring discharge of spring

Figure 5: Gullies at Tsephu

Figure 6: Location of the recharge area and Zaka spring on the Google Earth image.

Domsanye spring

Location: Dumsa nye, Jigmena, Mewang gang Gewog, Thimphu
Coordinates: N 27º 25' 59.52" E 89º 32' 18.35"
Elevation: 2424 m
Discharge: 6350.31 lpm (at 11.59 am, July 3, 2021), Rectangular-weir method
Household Dependent: 8
Population Dependent: 40
Status: No Change

Water Quality - Physical Analysis
pH: 7.79 | **Salinity:** 64.8 ppm | **EC:** 203 µs/cm | **Temperature:** 9.8°C |
TDS: 146 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 200 mg/l | **Phosphorus:** 0.9 mg/l |
Fluoride: 1 mg/l | **Chloride:** 0 mg/l

Field Facilitators
(From left to right):

Mrs. Sonam Lhaki (DoFPs)
Mr. Passang Tobgay (Tarayana)

Figure 1: Domsanye Spring

Hydrogeology:

This springshed is made up of a limestone layer and a granite layer. The limestone is weather and karstic in nature. Limestone layers with many fractures dip 65 - 75°northeast. Just below Domsanye spring, there is a granite layer, dipping 40° northwest. Domsanye spring emerges at the contact of the granite and limestone layers. Since the springs are emerging from the dissolving limestone it is classified as a karstic spring and is also identified as a contact spring. Both Domsanye spring and Gidagom forest management units (FMU) spring source share a recharge area, which is highly forested; the suitable recharge intervention in this area is digging shallow pits to allow more infiltration.

Hydrogeological Layout of Domsanye spring

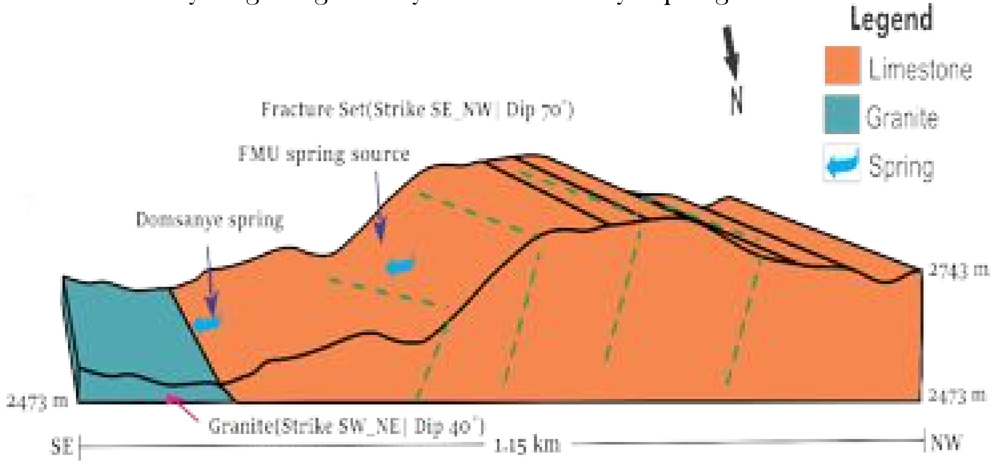


Figure 2: Hydrogeological Layout the of the Domsanye spring and Gidagom forest management units (FMU) spring source spring source

Potential Recharge Zone of the Domsanye spring and Gidagom

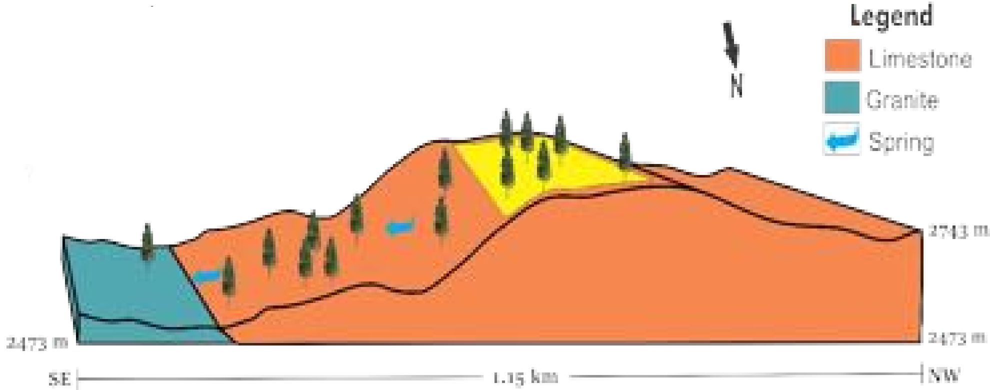


Figure 3: Potential Recharge Zone of the Domsanye spring and Gidagom FMU spring source

Figure 4: Lithology at Gidagom

Figure 5: Measuring dip and strike of rocks

Figure 6: Location of the recharge area and spring sources on the Google Earth image.

Gidagom forest management unit (FMU) spring source

Location: Dumsa nye, Jigmena, Mewang gang Gewog, Thimphu
Coordinates: N 27º 25' 59.52" E 89º 32' 18.35"
Elevation: 2619 m
Discharge: 1.292 lpm (at 1.18 pm, July 3, 2021), Volumetric method
Household Dependent: 8
Population Dependent: 40
Status: No Change, Perennial

Water Quality - Physical Analysis
pH: 8.14| **Salinity:** 61.9 ppm | **EC:** 201 µs/cm | **Temperature:** 9.8°C | **TDS:** 143 ppm

Chemical Analysis
Nitrate : 3 mg/l | **Iron:** 0 mg/l | **Hardness:** 88 mg/l | **Phosphorus:** 0.1 mg/l | **Fluoride:** 0.8 mg/l | **Chloride :** 14.18 mg/l

Field Facilitators (From left to right):

Mrs. Sonam Lhaki (DoFPS)
Mr. Passang Tobgay (Tarayana)
Mr. Jambay (Expert)

Figure 1: Gidagom FMU spring source

Chetoe Goenpa spring

Location: Chimethang kha, Jigmena, Mewang gang Gewog, Thimphu
Coordinates: N 27º 26' 39.05" E 89º 31' 46.7"
Elevation: 2598 m
Discharge: 3.052 lpm (at 3.21 pm, July 3, 2021),Volumetric method
Population Dependent: Bhutan Institute of Wellbeing(BIW)
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 8.06| **Salinity:** 92.7 ppm | **EC:** 296 µs/cm | **Temperature:** 12.5°C | **TDS:** 210 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 172 mg/l | **Phosphorus:** 0.3 mg/l | **Fluoride:** 0.9 mg/l | **Chloride:** 14.18 mg/l

Field Facilitators
(From left to right):

Mrs. Sonam Lhaki (DoFPs)
Mr Passang Tobgay (Tarayana)
Ms. Karma Uden (Tarayana)

Figure 1: Chetoe Goenpa spring

Hydrogeology:

This springshed is comprised of schists. Schist dips 45° towards the southwest. The spring emerges from thick debris along the western slope in the middle of a forested area. Chetoe Goenpa spring is classified as a depression spring. The schist beds act as the main aquifer for the spring. The recharge area for the spring is the area on the escarpment slope where the schist is exposed. The recommended work for recharging spring includes forest protection and construction of pits and staggered contour trenches for harvesting rainwater.

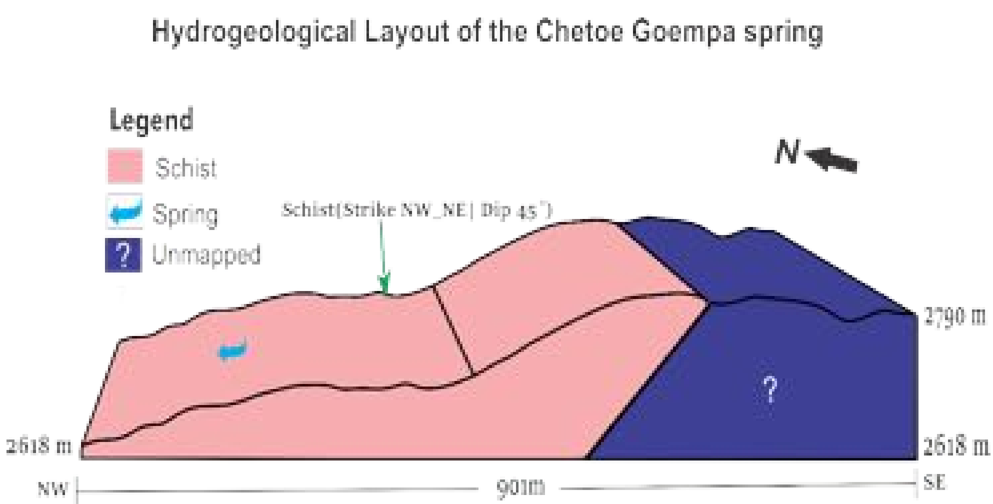


Figure 2: Hydrogeological Layout of the Chetoe Goempa spring

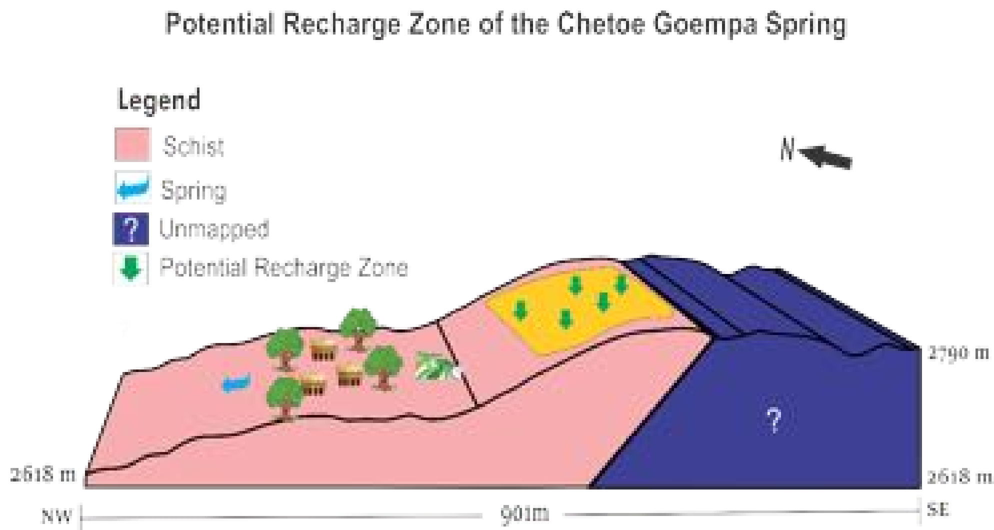


Figure 3: Potential Recharge Zone of the Chetoe Goempa spring

Figure 4: Measuring spring water quality

Figure 5: Measuring spring water discharge

Figure 6: Location of the recharge area and Chetoe Goempa spring on the Google Earth image.

Duesnas Khotsa spring

Location: Barshongtoe, Barshong Gewog, Tsirang
Coordinates: N 26º 55' 28.24" E 89º 51' 12.46"
Elevation: 1103 m
Discharge: 174.6 lpm (at 11.52 am, July 11, 2021), Volumetric method
Household Dependent: 6
Population Dependent: 30
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.25| **Salinity:** 43.5 ppm | **EC:** 127.8 µs/cm | **Temperature:** 18.6°C | **TDS:** 93.2 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 12 mg/l | **Phosphorus:** 0.3 mg/l | **Fluoride:** 0.8 mg/l | **Chloride:** 0 mg/l

Figure 1: Duesnas khotsa spring

Hydrogeology:

This springshed is comprised of alternating layers of schist and granite. The schist layers dominate and are weathered. Unconsolidated debris is deposited near the spring. Duesnas Khotsa Spring emerges from beneath the debris and is thus classified as a depression spring. There are multiple fractures responsible for the formation spring thus also classified as a contact spring. The schists and granites dip 35°- 45° towards the southwest. The recharge area for the springs is the upper reaches of the mountain and also extends along the fractures towards the northeast and southwest along the surface.

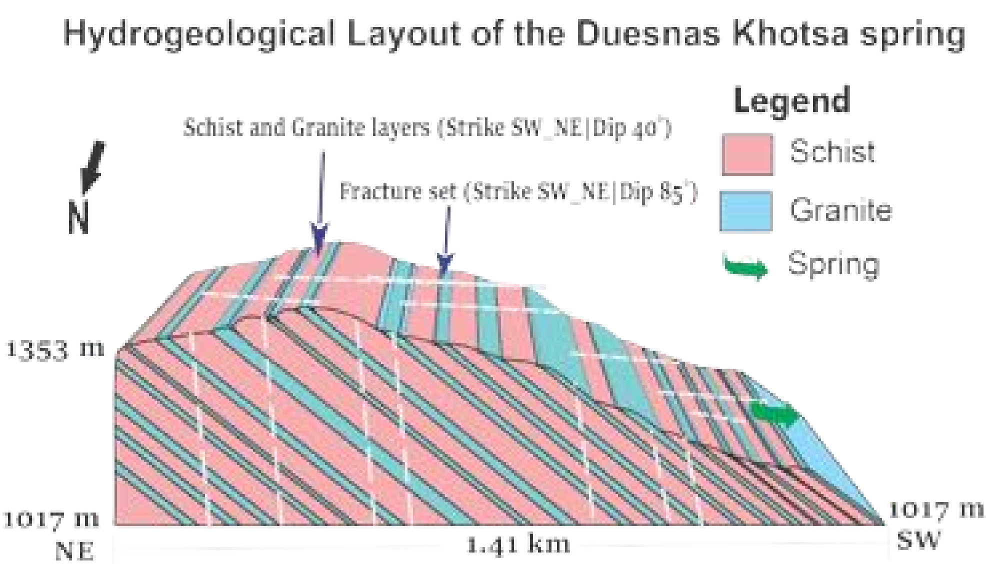


Figure 2: Hydrogeological Layout the of the Duesnas Khotsa spring

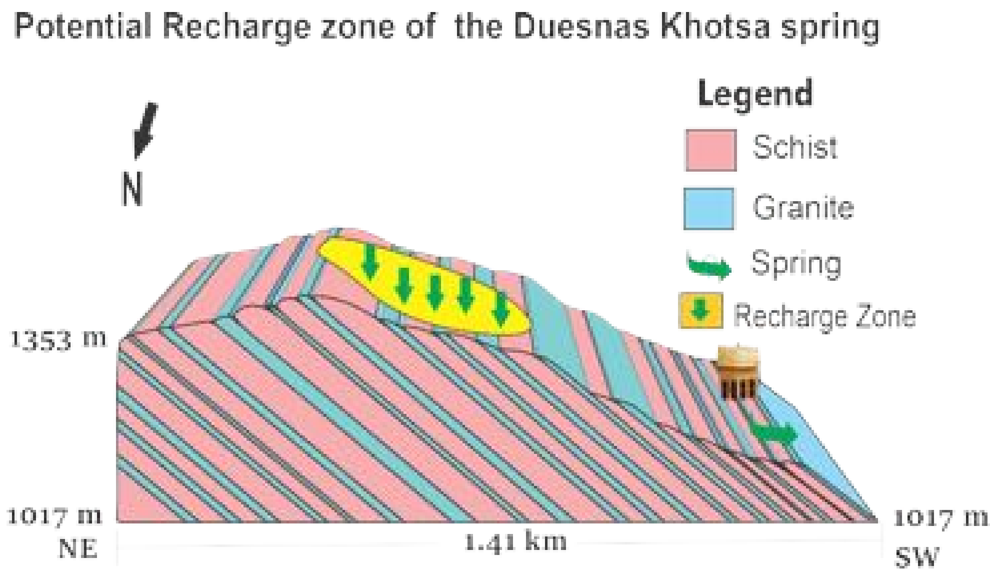


Figure 3: Potential Recharge Zone of the Duesnas Khotsa spring

Figure 4: Measuring spring water discharge

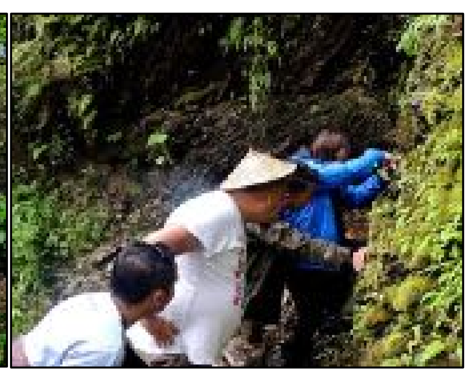


Figure 5: Measuring dip and strike of rocks

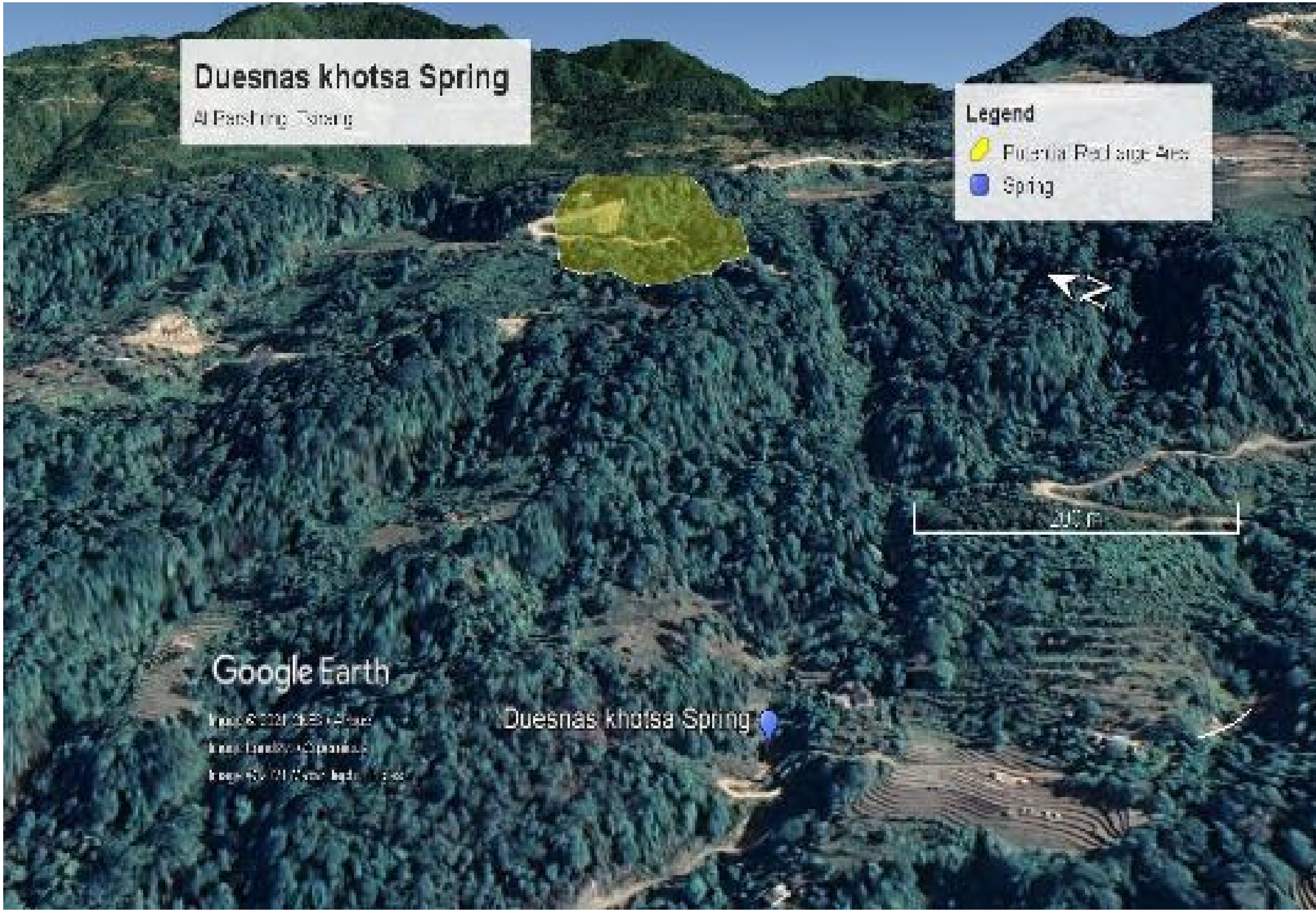


Figure 6: Location of the recharge area and Duesnas Khotsa spring on the Google Earth image.

Raikha Dara spring

Location: Barshongtoe, Barshong Gewog, Tsirang
Coordinates: N 26º 56' 6.97" E 90º 5' 55.97"
Elevation: 1404 m
Discharge: 15.77 lpm (at 2.29 pm, July 12, 2021), Volumetric method
Household Dependent: 5
Population Dependent: 25
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 5.8| **Salinity:** 33.3 ppm | **EC:** 94.1 µs/cm | **Temperature:** 17.6°C |
TDS: 66.8 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 96 mg/l | **Phos**
Fluoride: 1 mg/l | **Chloride:** 0 mg/l

Field Facilitators (from left to right):

Mr. Mondor Tamang,
Mr. Namagy, Tarayyana
Mr. Mon Bdr. Maya,
Mr. Santala Poudel (Gup)

Figure 1: Raikha Dara Spring

Hydrogeology:

This springshed is made of schists. The schist is permeable rock and forms a good aquifer for Raikha Dara spring. A thick layer of weathered materials and unconsolidated debris is deposited above the spring and Raikha Dara spring emerges from beneath the debris and is thus classified as a depression spring. The schists dip 20° - 30° towards the northwest. The recharge area for the spring falls within forested schist layers with thick unconsolidated materials.

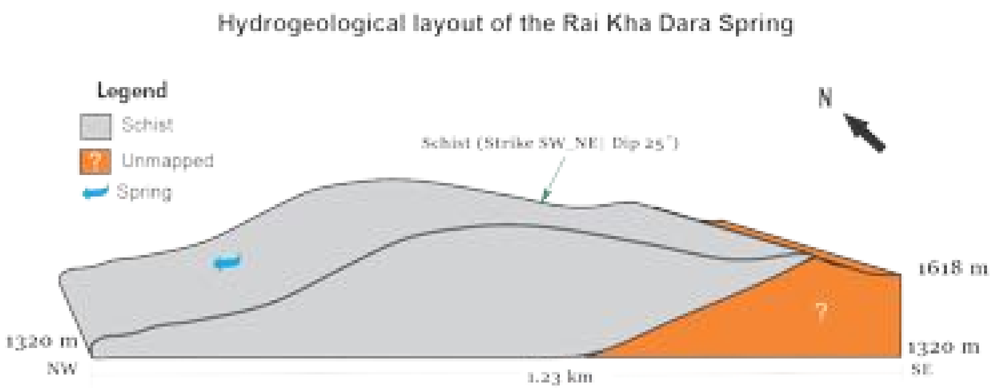


Figure 2: Hydrogeological Layout the of the Rai Kha Dara spring

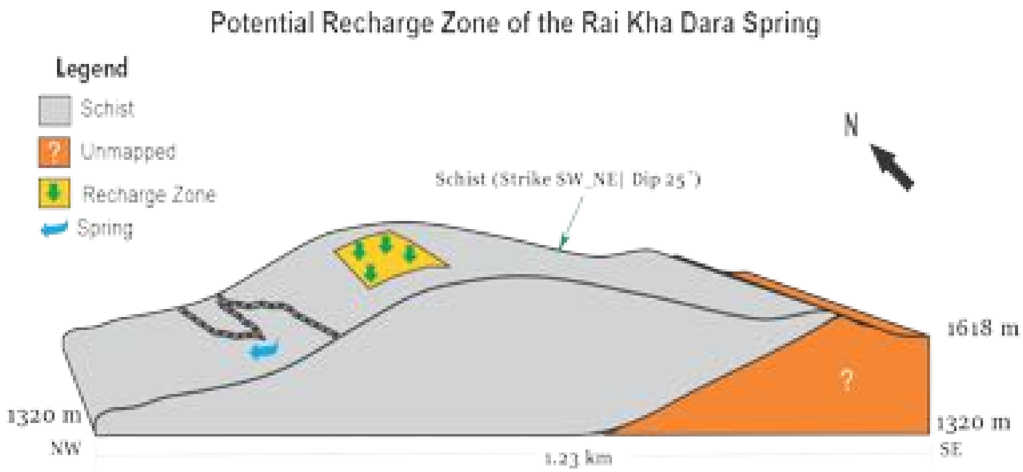


Figure 3: Potential Recharge Zone of the Rai Kha Dara spring

Figure 4: Measuring dip and strike of rocks

Figure 5: Field Officer measuring rocks

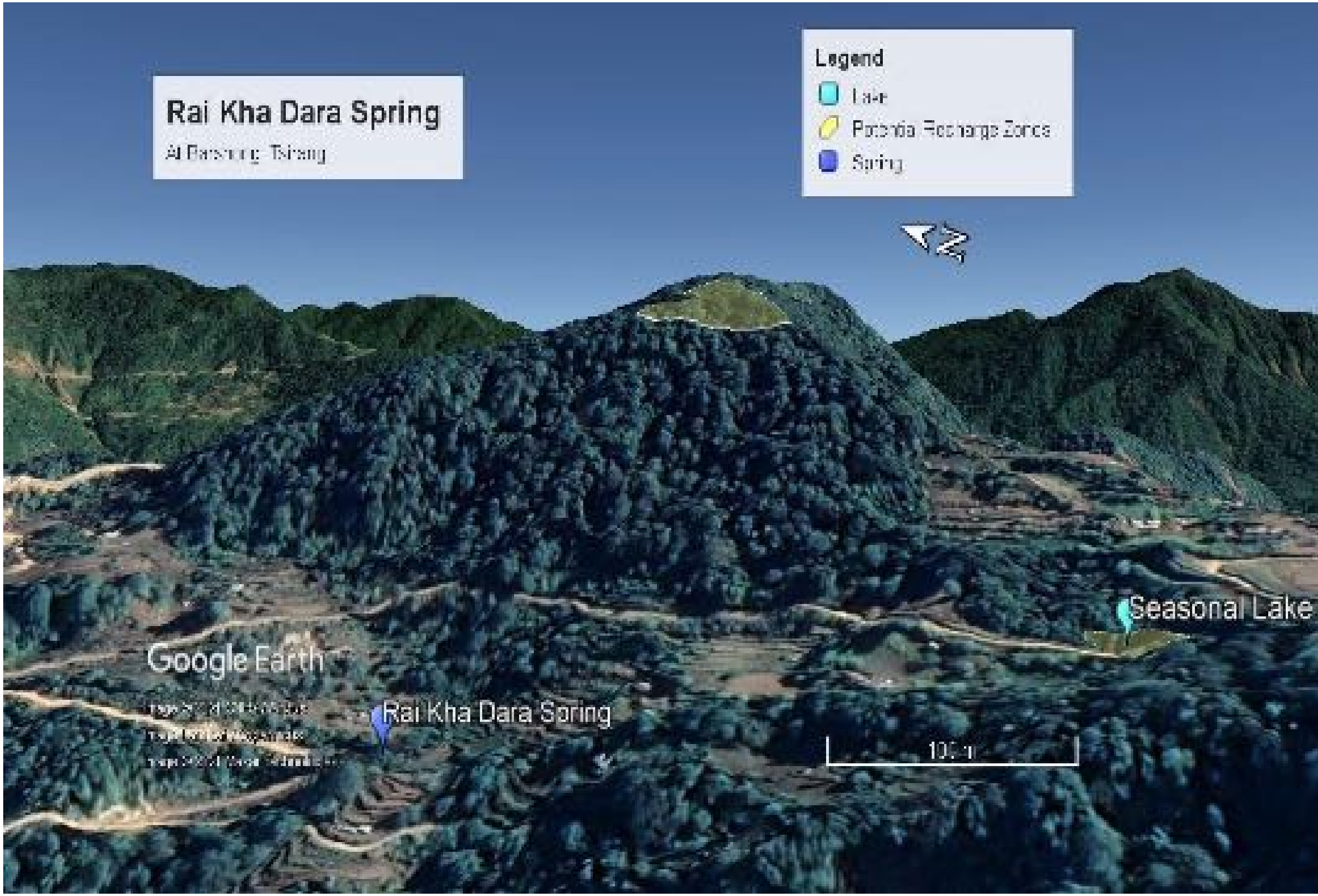


Figure 6: Location of the recharge area and Rai Kha Dara spring on the Google Earth image.

Dabethang spring

Location: Balakha, Semjong Gewog, Tsirang
Coordinates: N 27º 2' 21.7" E 90º 10' 33.71"
Elevation: 1862 m
Household Dependent: 10
Population Dependent: 60
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.14| **Salinity:** 26.2 ppm | **EC:** 73.3 µs/cm| **Temperature:** 15.5°C | **TDS:** 52.3 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 88 mg/l | **Phosphorus:** 0.1 mg/l | **Fluoride:** 0.9 mg/l | **Chloride:** 0 mg/l

Field Facilitators: Mr. Namgay (Tarayana) and Water source dependents

Figure 1: Dabethang spring

Hydrogeology:

This springshed is made up of schists overlying phyllite. A mantle of unconsolidated materials composed of schists and phyllite fragments with a wide range of grain sizes ranging from fine to coarse overlie the rock in the places. This debris and the schist acts as the aquifer for the Dabethang spring. The spring that emerges from the debris on the schists is classified as a depression spring. The area on the north-eastern slope about the spring is the recharge area for the spring.

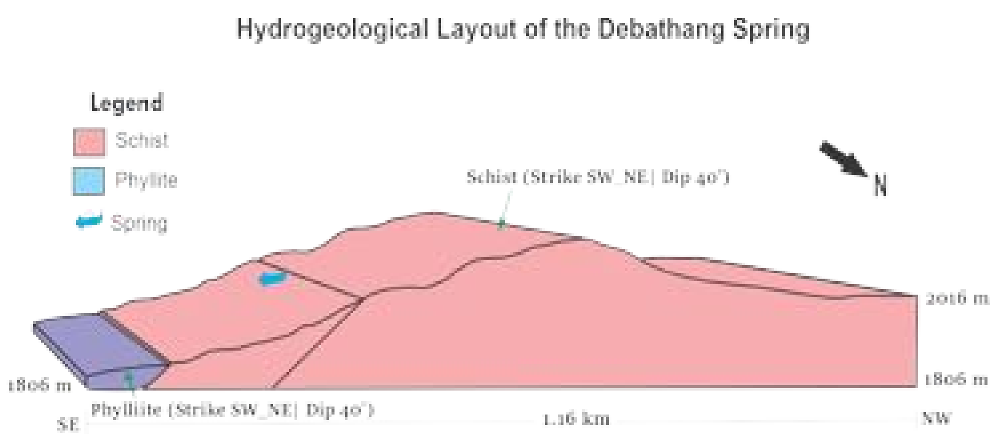


Figure 2: Hydrogeological Layout the of the Debathang spring

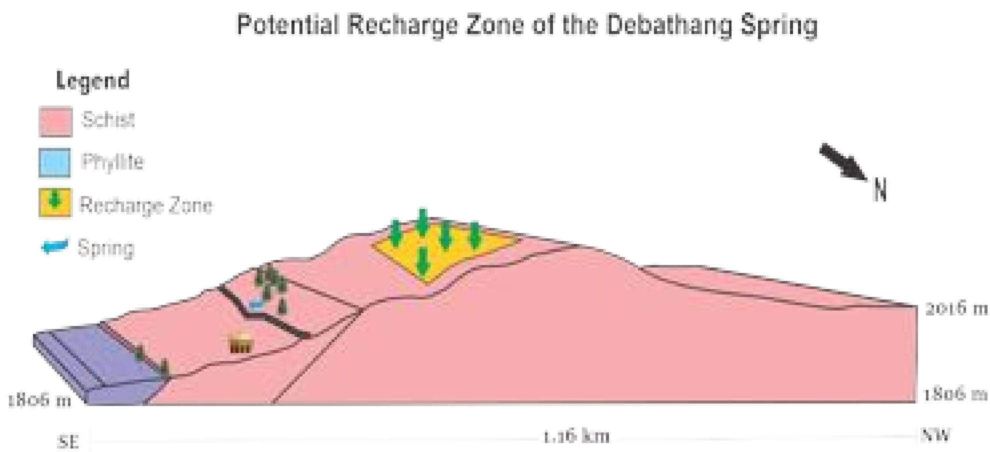


Figure 3: Potential Recharge Zone of the Debathang spring

Figure 4: Measuring discharge of spring

Figure 5: Measuring dip and strike of rocks

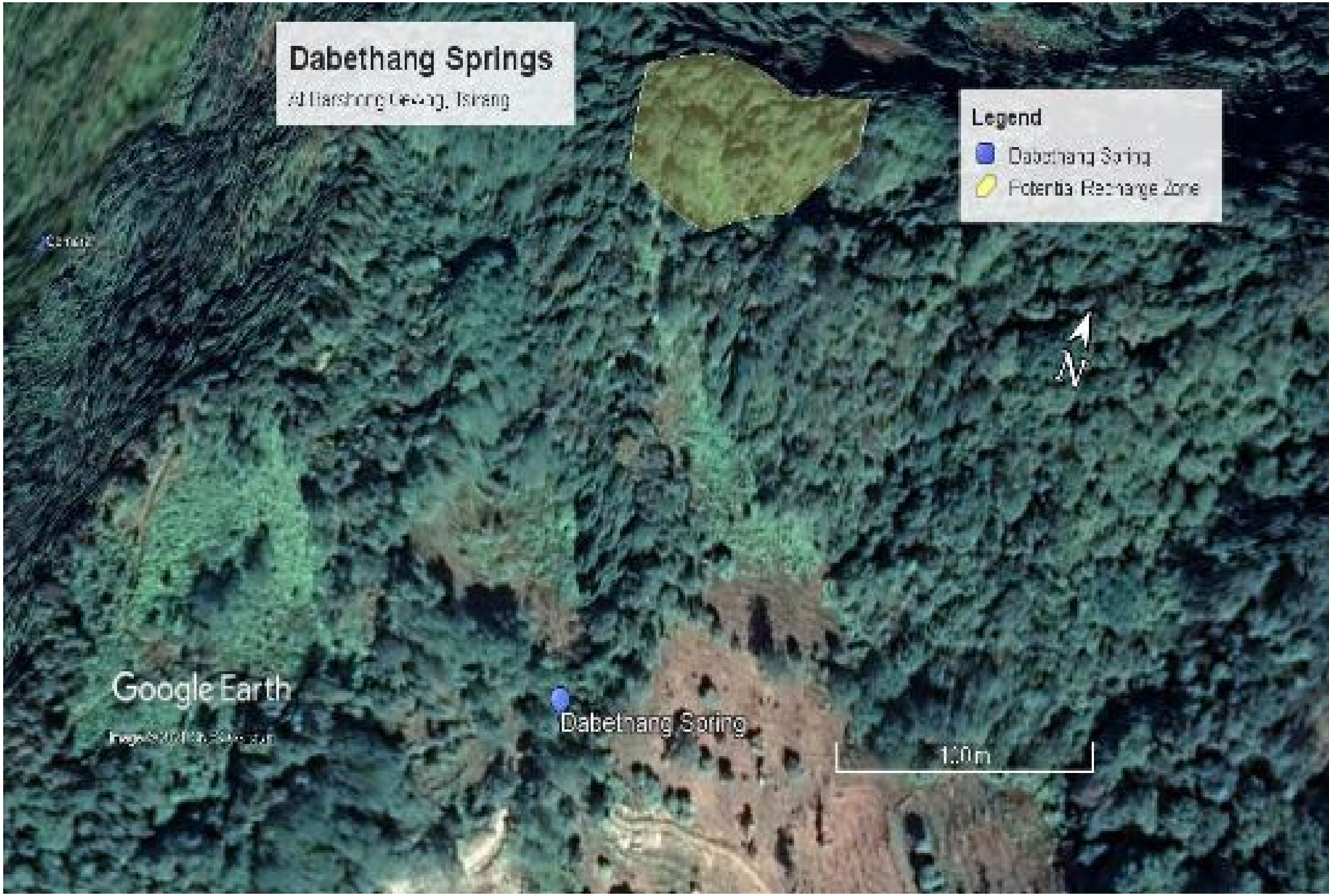


Figure 6: Location of the recharge area and the Dabethang spring on the Google Earth image.

Balukhop spring

Location: Balukhop, Semjong Gewog, Tsirang
Coordinates: N 27º 2' 16.3" E 90º 10' 40.48"
Elevation: 1805 m
Household Dependent: 40
Population Dependent: 260
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.6| **Salinity:** 55.8 ppm | **EC:** 104.6 µs/cm | **Temperature:** 15.7°C | **TDS:** 47.4 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 92 mg/l | **Phosphorus:** 0.3 mg/l | **Fluoride:** 0.8 mg/l | **Chloride:** 10.65 mg/l

Field Facilitators:

Mr. Namgay (Tarayana) and Water source dependents

Figure 1: Balukhop spring

Hydrogeology:

The dominant lithologies in this springshed are phyllite and schist dipping 40° towards southwest. The schist outcrops are exposed above Balukhop spring. The spring emerges from phyllites below the schist layer at the sharp depression, therefore this spring is classified as a depression spring. The schist-dominant ridge with forest cover forms the recharge area of the Balukhop spring.

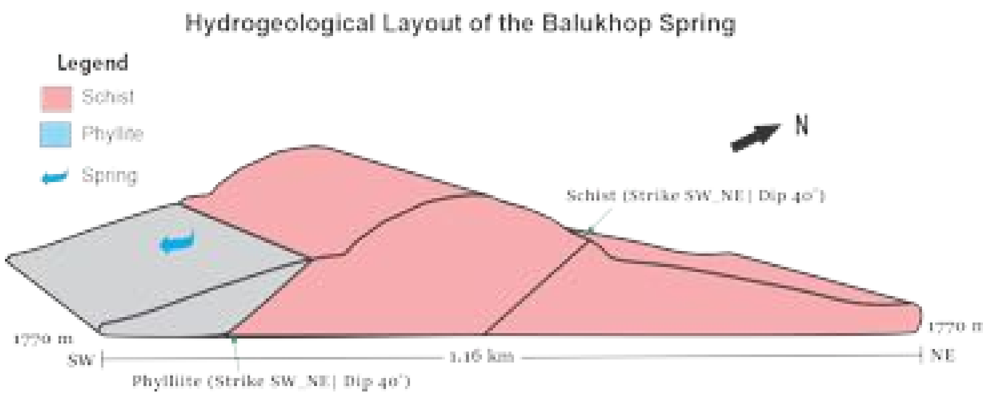


Figure 2: Hydrogeological Layout the of the Balukhop spring

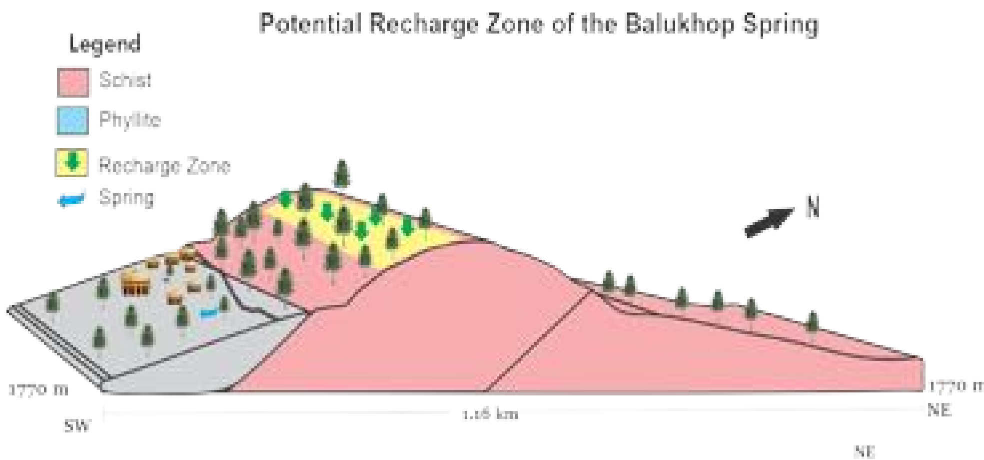


Figure 3: Potential Recharge Zone of the Balukhop spring

Figure 4: Measuring in-situ spring water quality

Figure 5: Measuring discharge of spring

Figure 6: Location of the recharge area and Balukhop springs on the Google Earth image.

Comara spring

Location: Khatoe (Upper Zomling), Semjong Gewog, Tsirang
Coordinates: N 27º 2' 28.46" E 90º 10' 11.6"
Elevation: 1656m
Household Dependent : 70
Population Dependent: 350
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.12| **Salinity:** 25.9 ppm | **EC:** 72.5 µs/cm | **Temperature:** 14.17°C | **TDS:** 51.2 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 400 mg/l | **Phosphorus:** 0.6 mg/l | **Fluoride:** 0.7 mg/l | **Chloride:** 0 mg/l

Field Facilitators:

Mr. Dil Bdr Raika (Water source dependent)
Mr. Namgay (Tarayana)

Figure 1: Comara spring

Soentoebsa Pani spring

Location: Soentoebsa, Tsirangtoe Gewog, Tsirang
Coordinates: N 27º 3' 36.79" E 90º 6' 25.6"
Elevation: 1303 m
Discharge: 3.53 lpm (at 11:00 am, July 13, 2021), Volumetric method
Household Dependent: 11
Population Dependent: 30
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 5.96| **Salinity:** 38.8 ppm | **EC:** 109.2 µs/cm | **Temperature:** 18.7°C | **TDS:** 77.5 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 88 mg/l | **Phosphorus:** 0.7 mg/l | **Fluoride:** 0.9 mg/l| **Chloride:** 0 mg/l

Figure 1: Soentoebsa Pani spring

Hydrogeology:

Soentoebsa Pani spring emerges on the north-western slope of the mountain ridge. The entire ridge is thickly forested and made up of granite and schist. The schists and phyllites dip 55° northwest and are highly weathered at places. This thick weathered debris mantle acts as an aquifer for the spring and thus Soentoebsa Pani spring is classified as depression spring. The recharge areas for this spring fall on forested schists and unconsolidated materials toward the southeast.

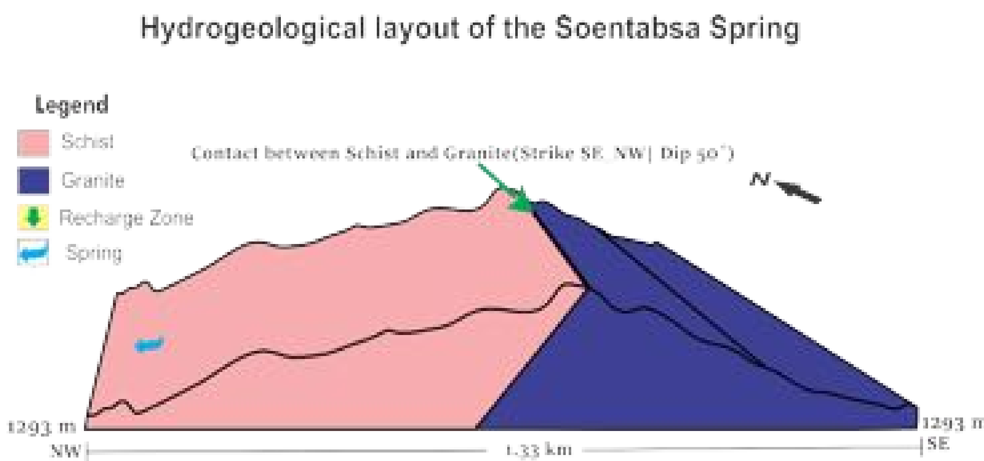


Figure 2: Hydrogeological Layout the of the Soentabsa Pani spring

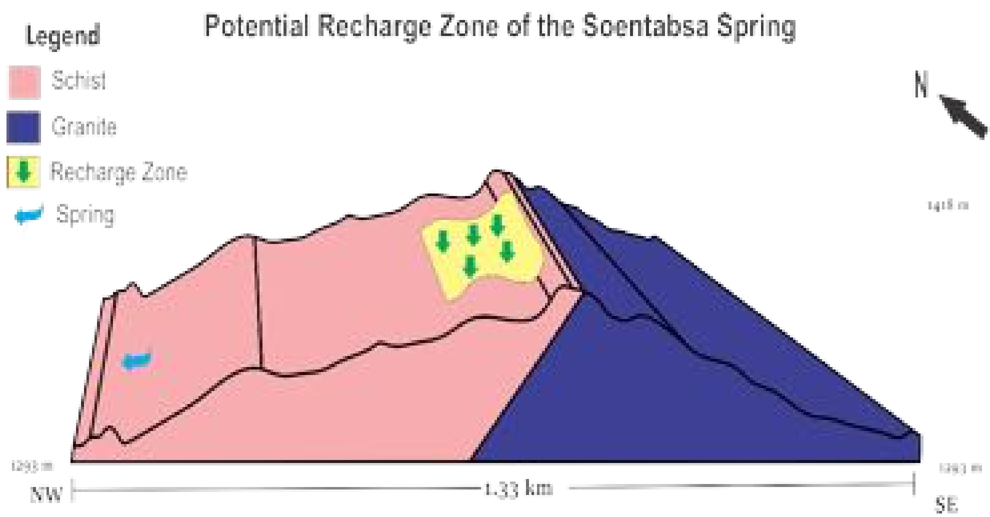


Figure 3: Potential Recharge Zone of the Soentabsa Pani spring

Figure 4: Explaining lithology at Tsirangtoe

Figure 5: Measuring of spring water quality

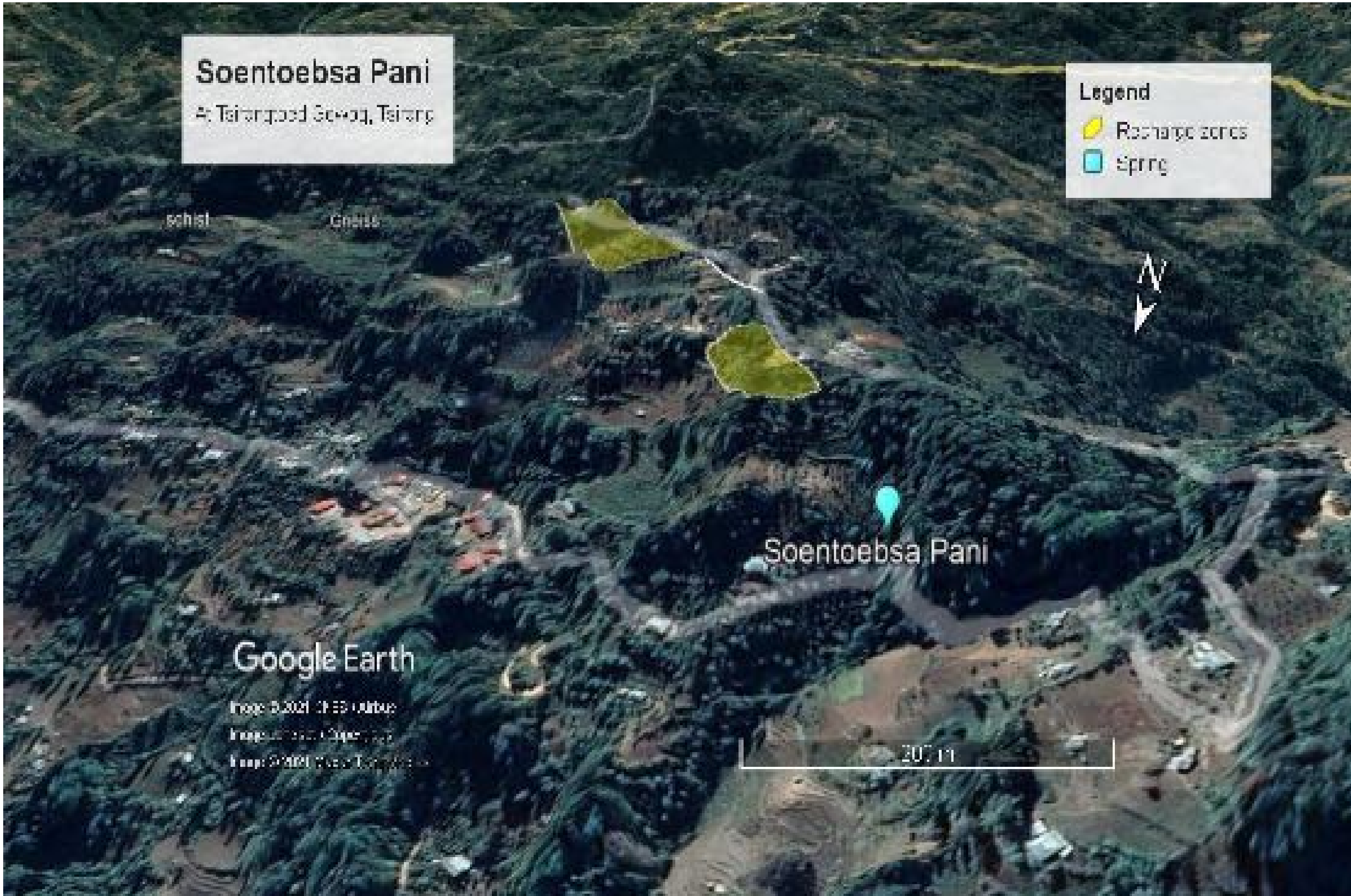


Figure 6: Location of the recharge area and Soentoesa Pani on the Google Earth image.

Tsirang Kholsa spring

Location: Soentoebsa, Tsirangtoe Gewog, Tsirang
Coordinates: N 27º 3' 41.8" E 90º 7' 26.18"
Elevation: 1148 m
Discharge: 3.468 lpm (at 3:35 pm, July 13, 2021), Volumetric method
Population Dependent: 60
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 7.35| **Salinity:** 28.5 ppm | **EC:** 75.2 µs/cm | **Temperature:** 19.5°C | **TDS:** 53.5 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 252 mg/l | **Phosphorus:** 0.4 mg/l | **Fluoride:** 1 mg/l | **Chloride:** 0 mg/l

Field Facilitators:

Mr. Wangchuk
Mr. Tenzin Zangpo
Mr. Nima Dorji
Mr. Nidup Tenzin
Mr.Tak Bdr Rai
Mr. Ugyen Dorji

Figure 1: Tsirang Kholsa spring

Hydrogeology:

The entire springshed is made up of schists with a thin granite layer observed below Tsirang Kholsa spring. The schist dips 10° southwest and has parallel vertical fractures and other fracture sets dipping 50° to 60° to the southeast are observed. Tsirang Kholsa spring emerges on the southwest slope of the mountain from beneath thick colluvium. The recharge area for this spring falls on schists and unconsolidated materials toward the southeast. The spring is classified as a depression spring and the location of the recharge area of the aquifer is above the spring beyond a farm road. Rainwater runoff from this farm road could be directed to the aquifer for recharging the spring after ensuring that it is clean and will not compromise water quality. For example, animal manure or excess nutrients from the road could impact water quality and unconsolidated materials toward the southwest.

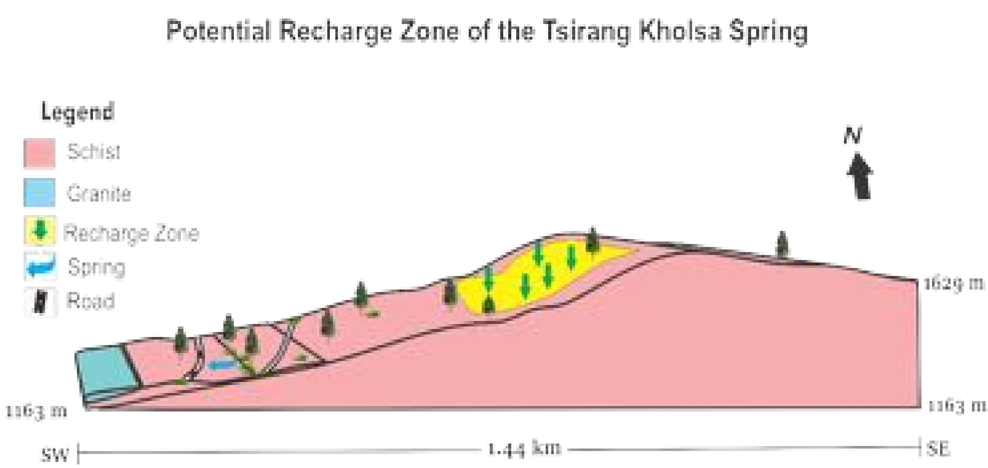


Figure 2: Hydrogeological Layout the of the Tsirang Kholsa spring

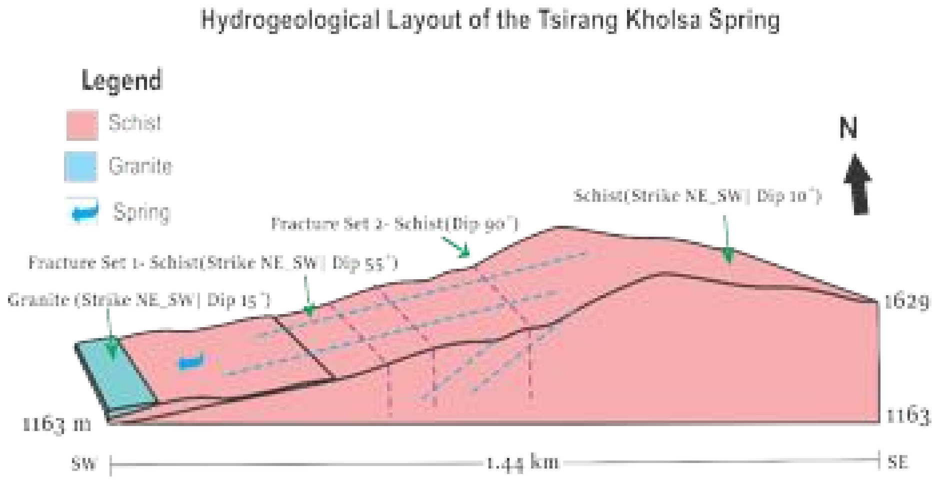


Figure 3: Potential Recharge Zone of the Tsirang Kholsa spring

Figure 4: Explaining dip and strike of rocks

Figure 5: Learning lithology at Tsirangtoe

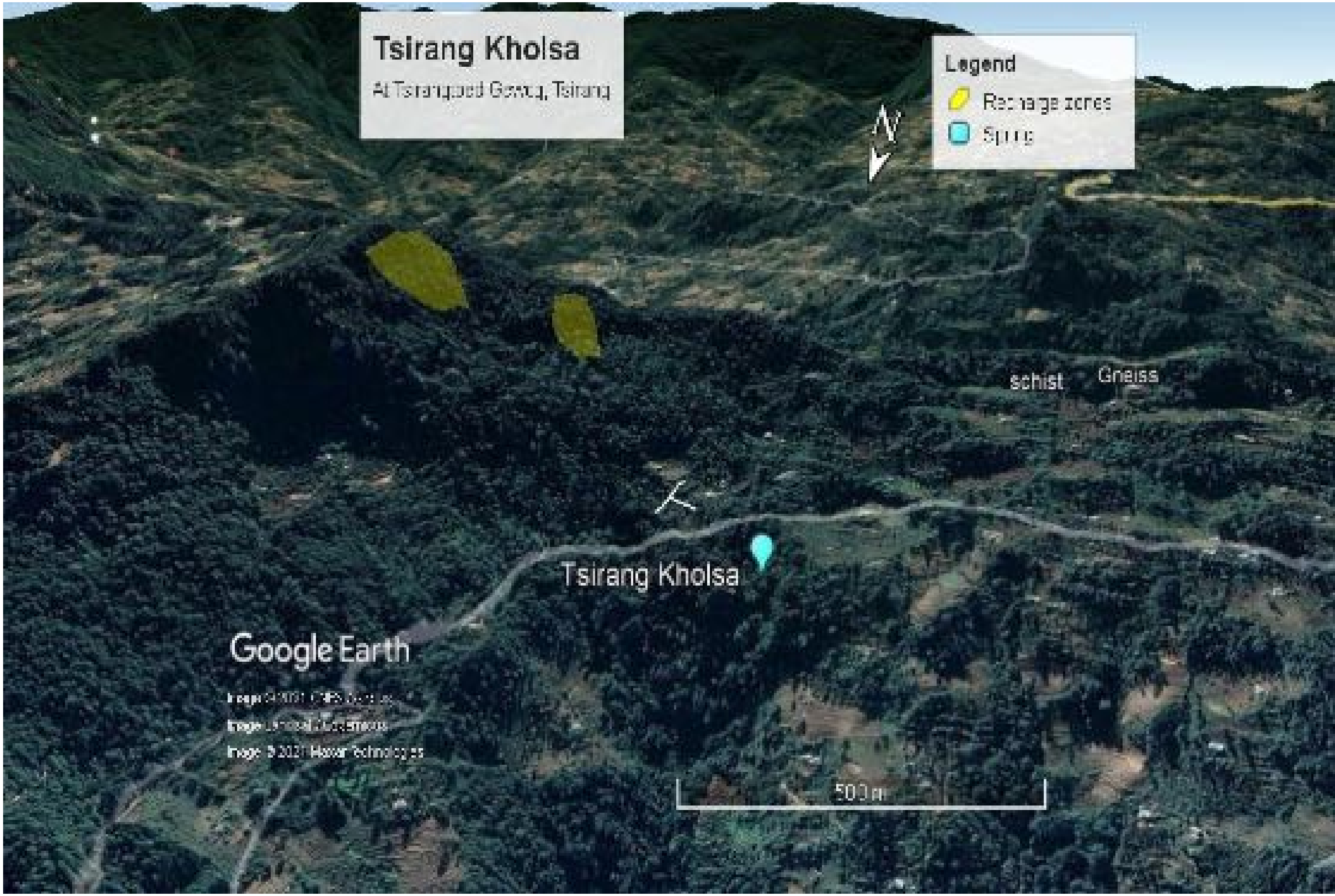


Figure 6: Location of the recharge area and Tsirang Kholsa spring on the Google Earth image.

Bodhugang spring

Location: Tali, Tali Kilkar, Nangkor Gewog, Zhemgang
Coordinates: N 27º 10' 41.41" E 90º 45' 54.43"
Elevation: 1887 m
Discharge: 4.362 lpm (at 11.43 pm, July 17, 2021), Volumetric method
Household Dependent: 35
Population Dependent: 250
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.6| **Salinity:** 14.3 ppm | **EC:** 35.6 µs/cm | **Temperature:** 11.6°C |
TDS: 25.6 ppm

Chemical Analysis
Nitrate : 4 mg/l | **Iron:** 0 mg/l | **Hardness:** 120 mg/l | **Phosphorus:** 0.6 mg/l|
Fluoride: 1.3 mg/l | **Chloride:** 0 mg/l

Field Facilitators: Mr. Passang Tobgay (Tarayana)

Figure 1: Bodhugang spring

Hydrogeology:

Bodhugang spring originates in an area that is highly forested. Granite sandwiched between schist layers is exposed at the surface and is highly weathered. Schists and granite dip 15° to 30° to the northwest. A mass of debris with thick trees and shrubs is deposited above the spring. The spring that emerges from beneath the unconsolidated debris and is classified as a depression spring. The recharge area for this spring falls on schists and unconsolidated materials toward the southeast.

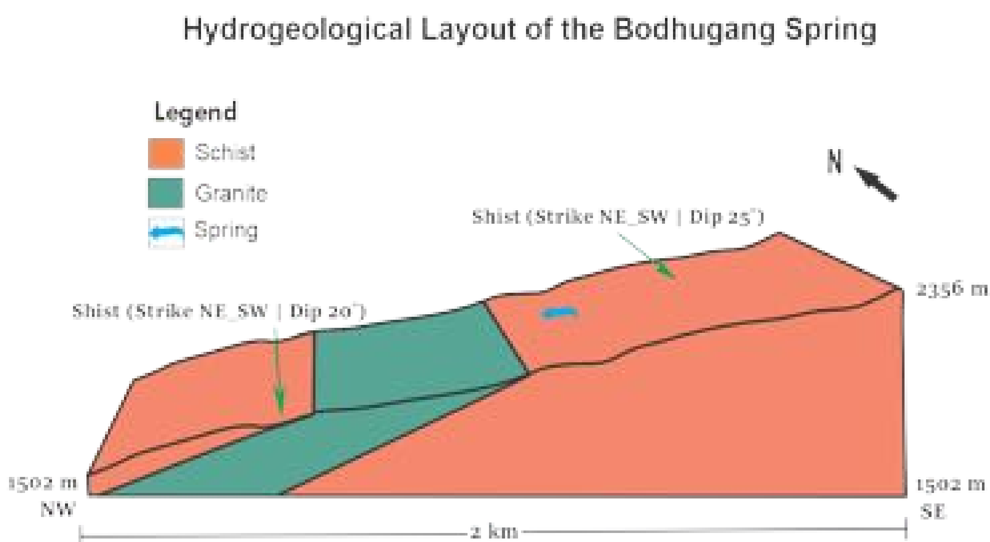


Figure 2: Hydrogeological Layout the of the Bodhugang Spring

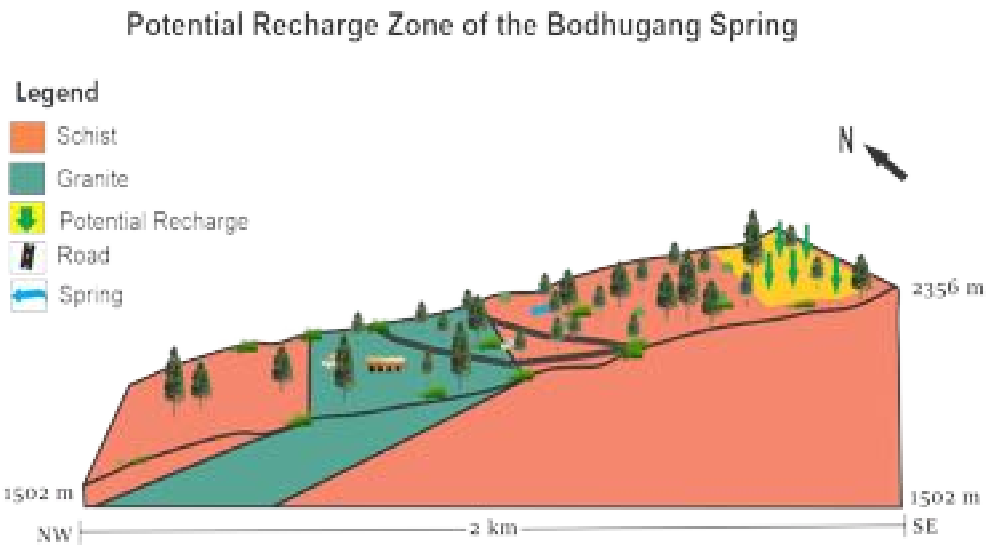


Figure 3: Potential Recharge Zone of the Bodhugang spring

Figure 4: Showing dip and strike of rocks

Figure 5: Lithology at Tali

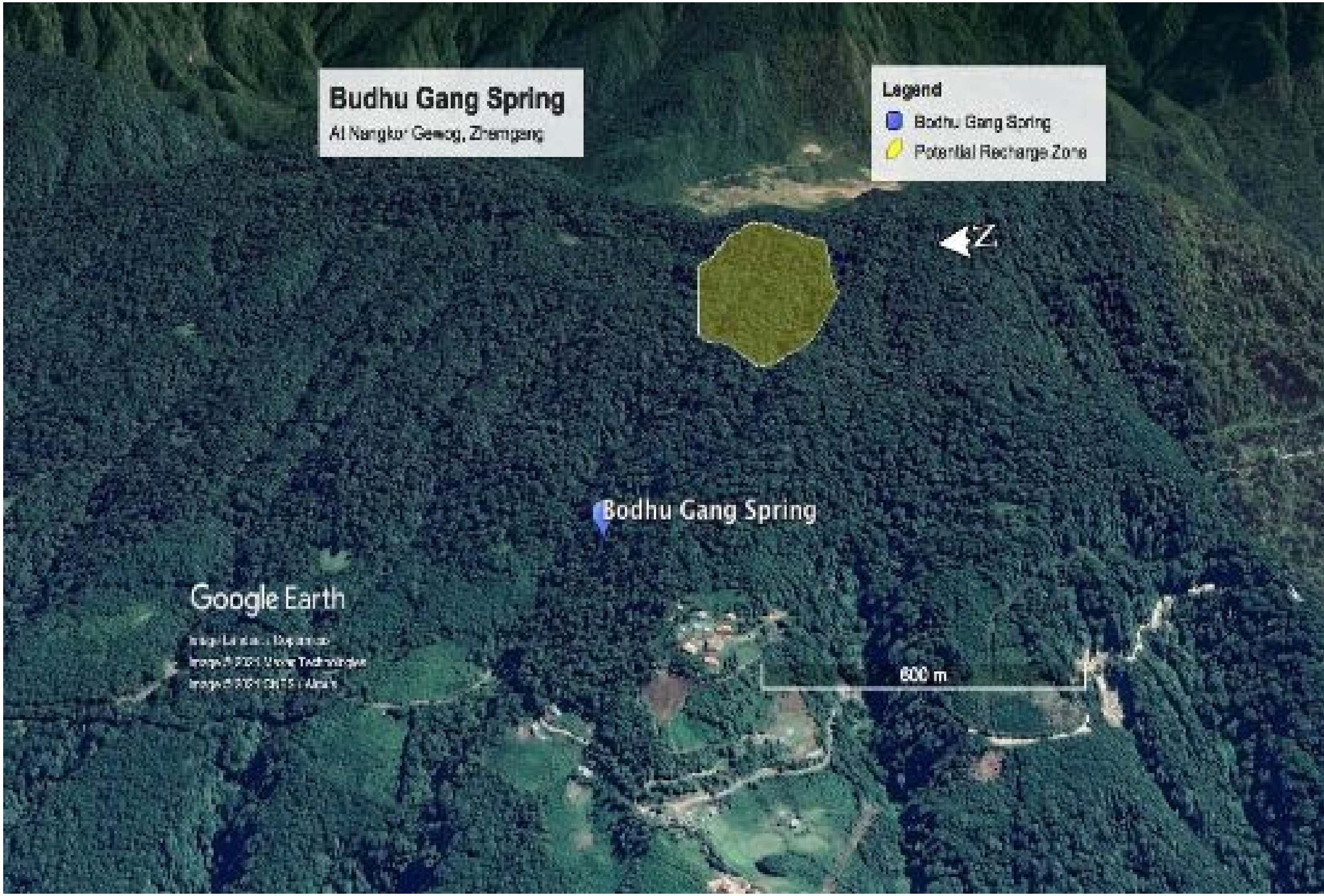


Figure 6: Location of the recharge area and Bodhugang spring on the Google Earth image.

Song They spring

Location: Kilkhar, Tali Kilkhar, Nangkor Gewog, Zhemgang
Coordinates: N 27º 12' 42.01" E 90º 38' 31.31"
Elevation: 1671 m
Discharge: 2.668 lpm (at 5.00 pm, July 17, 2021), Volumetric method
Household Dependent: 55
Population Dependent: 430
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 5.85| **Salinity:** 15.5 ppm | **EC:** 37.6 µs/cm | **Temperature:** 13.1°C |
TDS: 26.4 ppm

Chemical Analysis
Nitrate : 10 mg/l | **Iron:** 0.3 mg/l | **Hardness:** 80 mg/l | **Phosphorus:** 0.8 mg/l |
Fluoride: 0.6 mg/l | **Chloride:** 0 mg/l

Field Facilitators:

Mr. Passang Tobgay (Tarayana)
Mr. Tshering Norbu
Mrs. Leki Zangmo (Tshokpa)

Figure 1: Songthey Spring

Hydrogeology:

The springshed consists of schists at the top and granite below the spring. The layers of schist and granite dip 20° to 60° to the northwest. These springs emerge from weathered materials of schist layers, and thus they are depression springs. The more permeable schist acts as an aquifer for recharging Songthey spring and another spring source for the school located at similar elevations and these two springs share a common aquifer. The recharge area is located towards the southeast and recharging this area ensures recharging of both springs. A spring dependency population of this spring is comparatively higher among other water sources, therefore, the focus of intervention in this spring could generate substantial benefit for the communities.

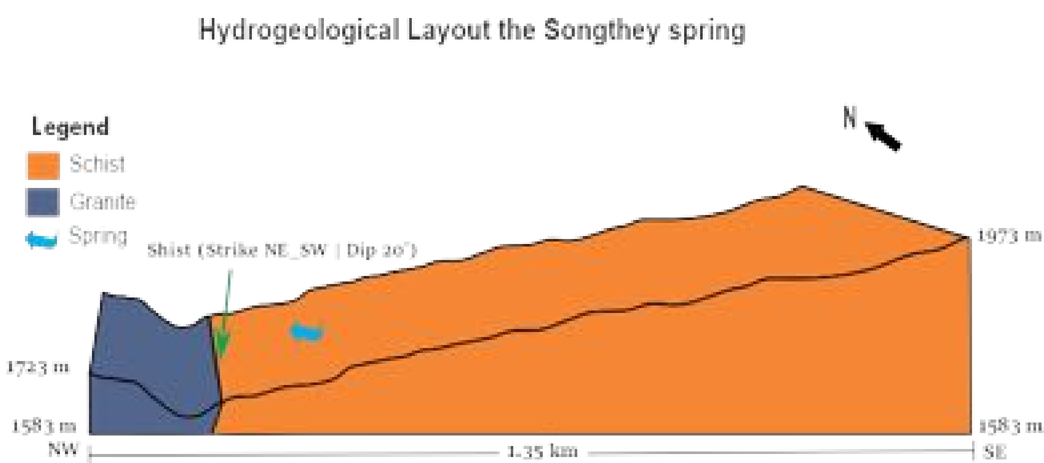


Figure 2: Hydrogeological Layout the of the Song They spring

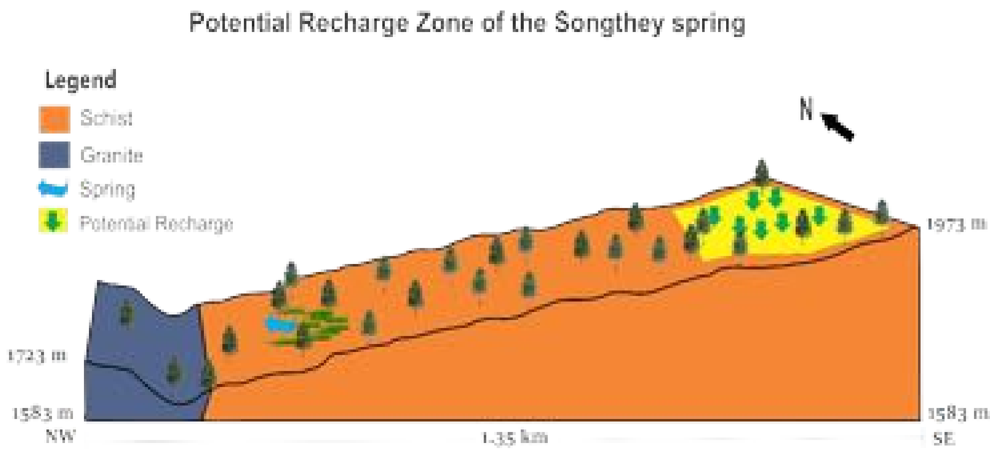


Figure 3: Potential Recharge Zone of the Song They spring

Figure 4: Showing measurement of rocks

Figure 5: Measuring rocks with Brunton compass

Figure 6: Location of the recharge area and Song They spring on the Google Earth image.

Tamala Tsho (lake)

Location: Tamala, Tama, Trong Gewog, Zhemgang
Coordinates: N 27º 5' 9.74" E 90º 38' 31.31"
Elevation: 2062 m
Population Dependent: For Animals
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 6.92| **Salinity:** 13.6 ppm | **EC:** 28.2 µs/cm| **Temperature:** 17.6°C |
TDS: 16.5 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0.1 mg/l | **Hardness:** 128 mg/l | **Phosphorus:** 0.4 mg/l |
Fluoride: 1.2 mg/l | **Chloride:** 0 mg/l

Field Facilitators:
(from left to right)

Mr. Ugyen Lhendrup
Mr. Passang Tobgay

Figure 1: Tamala Tsho

Hydrogeology:

The catchment area of Tamala lake comprises schist and granite layers. Thick, forested, unconsolidated debris overlies the granite and forms the recharge area of the lake. The schists and granites dip 20° - 30° towards north feeding Tamala lake which has experienced a significant decline in water level.

Recommendations:

- Dig shallow pits at different locations within the catchment of the lake to harvest rainwater.
- Divert rainwater from the road to Tamala lake to revive the dying lake which is indeed a recharge zone for nearby springs in the area. Filtering this water first could help remove potential contaminants. Intervention must not introduce nutrients to the lake either or change the water temperature with too much overland flow. This could encourage algal growth in the lake.

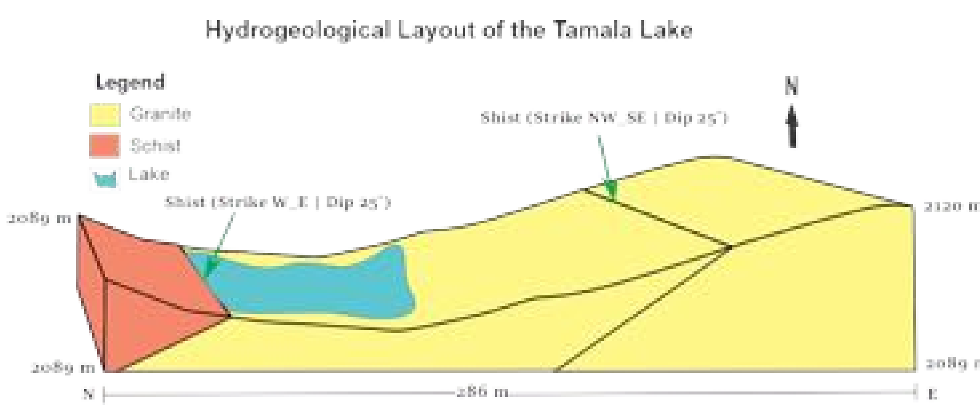


Figure 2: Hydrogeological Layout the of the Tamala Lake

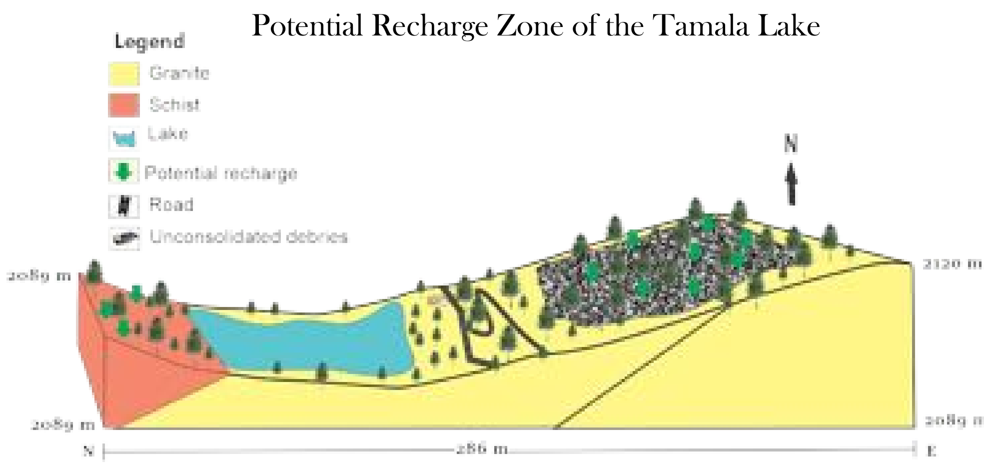


Figure 3: Potential Recharge Zone of the Tamala Lake

Figure 4: Measuring dip and strike of rocks

Figure 5: Measuring of spring water quality

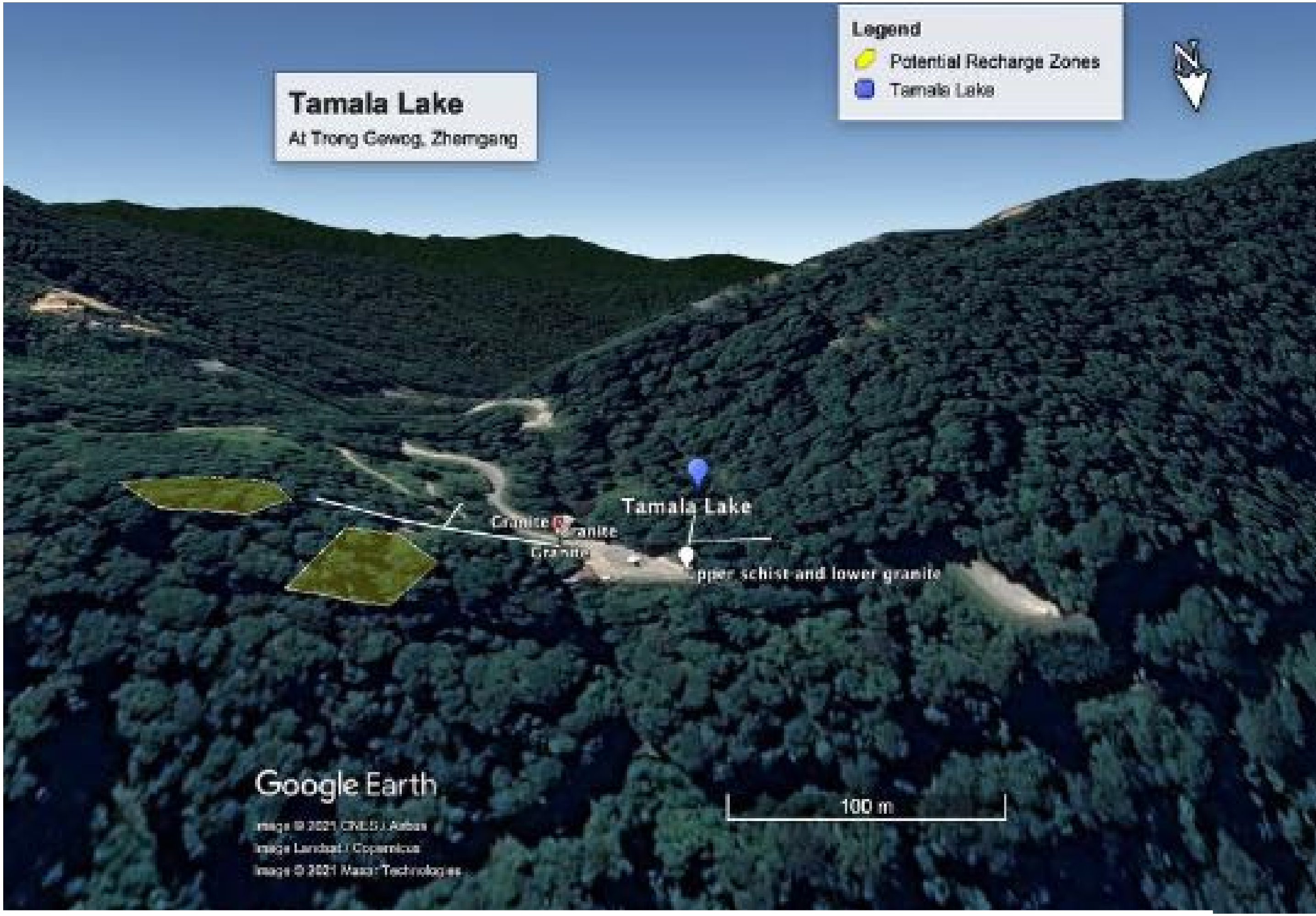


Figure 6: Location of the recharge area and Tamala lake on the Google Earth image.

Tali Tsho (lake)

Location: Tali, Nangkhor Gewog, Zhemgang
Coordinates: N 27º 10' 16" E 90º 44' 47.22"
Elevation: 1742 m
Population Dependent: For Animals
Status: Dying, Perennial

Water Quality - Physical Analysis
pH: 5.6 | **Salinity:** 15.9 ppm | **EC:** 20 µs/cm | **Temperature:** 14.3°C |
TDS: 22.7 ppm

Chemical Analysis
Nitrate : 0 mg/l | **Iron:** 0.7 mg/l | **Hardness:** 156 mg/l | **Phosphorus:** 0.35 mg/l |
Fluoride: 1.3 mg/l | **Chloride:** 0 mg/l

Figure 1: Tali Tsho (lake)

Song They Om river

Location: Kilkhar, Tali kiklar, Nangkhor Gewog, Zhemgang
Coordinates: N 27º 12' 42.01" E 90º 46' 36.88"
Elevation: 1580 m
Population Dependent: Ngajur Pema Chopheling Dratshang
Status: Dying, Perennial river

Water Quality - Physical Analysis
pH: 6.7 | **Salinity:** 26.8 ppm | **EC:** 15.6 µs/cm | **Temperature:** 16.2°C |
TDS: 37.8 ppm

Chemical Analysis:
Nitrate : 0 mg/l | **Iron:** 0 mg/l | **Hardness:** 180 mg/l | **Phosphorus:** 0.3 mg/l |
Fluoride: 0.8 mg/l | **Chloride:** 0 mg/l

Field Facilitators (from left to right):

Mr. Passang Tobgay (Tarayana)
Mr. Phuntsho Dorji

Figure 1: SongThey Om river

8. Water Quality

The descriptive statistics of the physicochemical parameters based on 4 lakes, 1 river, and 24 springs as compared with national and international water quality guidelines are shown in Tables 8.1 and 8.2. Most of the values adhere to the permissible limit and those slightly higher are because samples were collected from spring outlets, so it can be concluded that the water is suitable for domestic use, drinking, and irrigation.

As of now, water quality is good because sources and recharge areas are located deep in thick forests away from anthropogenic disturbances. However, they may invite zoonotic diseases to the communities if they are left unfenced.

Table 8.1: International water quality standard guidelines against present study

Parameter	WHO	BDWQS	BIS	European standard	Present study report (min. and max.)
pH	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	5.6-8.2
EC	400	800	400	400	22.7-649.2
TDS	300	-	500	-	15 - 534
Hardness	100	-	600	-	12-1200
Chloride	250	50	250	250	0-81.45
Phosphorous	5	-	-	-	0.08-1
Nitrate	5	10	45	-	0-10
Iron	0.3	0.3	0.3	0.3	0-3
Fluoride	1.5	1	1.5	-	0.2-1.5

Source: WHO (2006). Bhutan Drinking Water Quality Standard (BDWQS). BIS=Bureau of Indian Standards (2020), European standard (1997)

The skewness and kurtosis of a sample were assessed in order to determine if it came from a normal distribution. The values of these statistics outside the range of −2 to +2 indicate significant departures from normality. A statistical analysis of the data showed that most of the variables in the original dataset were not normally distributed, except for fluoride, pH, and phosphorus. A summary of the basic statistics of the water quality data set is presented in Table 8.2.

Table 8.2. Descriptive statistics of water quality parameters of springs and lake samples

Parameters	Count	Min	Max	Mean	Std. error	Variance	Stand. dev	Median	Skewness	Kurtosis
pH	29	5.6	8.2	6.97	0.14	0.59	0.77	6.92	-0.12	-1.14
TDS (ppm)	29	15.9	534	116.32	21.59	13519.56	116.27	66.5	1.93	4.63
Temp (°C)	29	6.8	29	15.53	0.75	16.40	4.05	15.1	1.25	4.17
Salinity (ppm)	29	13.6	239	55.48	9.27	2494.12	49.94	33.3	2.05	5.53
EC (µS/cm)	29	22.7	649.2	162.39	27.97	22691.05	150.64	96.8	1.54	2.43
Nitrate	29	0	10	0.59	0.38	4.11	2.03	0	4.07	17.70
Iron	29	0	3	0.3	0.13	0.53	0.73	0	3.03	8.83
Hardness	29	12	1200	196.83	44.78	58151.58	241.17	128	3.08	10.99
Phosphorus	29	0.03	1	0.35	0.05	0.07	0.26	0.3	0.98	0.15
Fluoride	29	0.2	1.5	0.84	0.06	0.09	0.30	0.8	0.55	0.63
Chloride	29	0	51.54	11.82	3.60	376.20	19.40	0	2.08	4.83

The Pearson Correlation coefficient measures the relationship between two variables. A correlation matrix for the selected parameters is shown in Figure 8.3. It is a simple measure of how well one variable predicts the other (Bahar and Reza, 2010). The salinity, TDS, and EC exhibited high positive correlations (blue-colored boxes). There is a correlation between these two characteristics of spring water, indicating that the ions are derived from the same source. Edet, Ukpong, and Nganje (2013) also found a similar result in the water quality evaluation in southeastern Nigerian river systems.

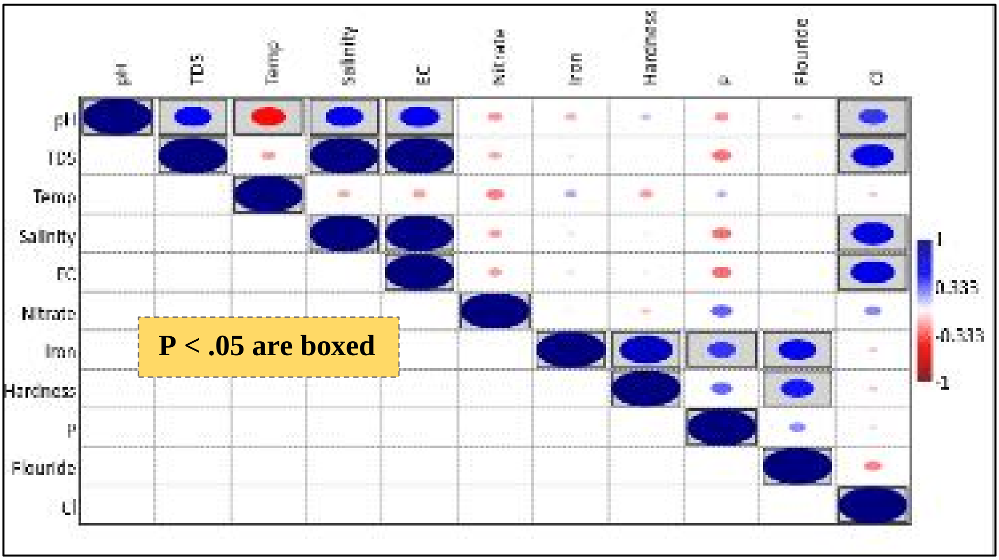


Figure 8.3. Correlation matrix of water quality variables (*n = 29*)

Although this study concludes that springs in Bhutan are of good quality, it is still necessary to analyse both the physical and chemical parameters of water quality in different seasons for selected springs and lakes to provide a benchmark and protect groundwater. Thus, this study suggests that scepticism about water quality is unwarranted since tested water is of high quality. In the future, however, water quality may deteriorate without correct interventions, so continual diligence and protection of recharge areas is needed.

9. Recommendations and proposed way forward

Prior to any land-use type conversion activities, such as road construction, it is recommended to identify the recharge areas for the community's drinking water. Considering spring recharge areas are defined largely by sub-surface hydrogeological characteristics, their location cannot be predetermined or assumed, putting water sources at risk. It is necessary to protect recharge areas to ensure that rainwater is able to percolate the local aquifer for drinking water. In conclusion, the following recommendations and actions are offered:

1. There is a need for a paradigm shift in how water sources are protected. There must be a shift of focus from the discharge areas protection through fencing and plantation around water sources to the recharge areas protection in the mountainous region.
2. For important water sources, the recharge areas are to be demarcated based on hydrogeological studies, However, the limitation of confirming the recharge areas should be supplemented by isotropic or dye tracing studies on the identified areas. It is possible to determine what developments have taken place in the recharge areas affecting the flow of freshwater, such as the drying up of lakes and spring sources.
3. It is imperative to understand where the source water comes from and how it is recharged in order to revitalize and restore dried-up lakes and springs. Planting trees on open spaces should not be

considered as a universal solution since it could pump more water from the aquifer and reduce inflow to surface water features.

4. The flow of mountain springs is highly influenced by local geology, so studying lithology in the area is an important part of protecting water sources. In addition, types of rocks, their directions, and discontinuities like faults and fractures should be identified and recorded.
5. We do not recommend the construction of water tanks or the cutting and planting of trees closer to water sources, since this could alter the orientation of the lithology. Consequently, the springs and lakes will shift or dry out as a result of new fractures feeding the springs.
6. We undertook this research as part of a community-engaged research project, and the results need to be communicated back to communities with issues of dry water sources. Our proposal is to conduct a series of awareness campaigns on the importance of recharge areas and protection of these areas from development activities such as road and building construction. It was vital to the success of this project to consult communities at the earlier stages. Their knowledge of springs greatly contributed to its success. The community will be able to protect these recharge zones from future damage if the information about these zones is available in books at the Gewog centre.

7. The protection of springs and lakes depends on the cooperation of communities. They need to be involved in setting up a long-term spring monitoring system in terms of both quality and quantity. Engaging them will help them to develop a sense of belonging and a better appreciation of this project and future projects related to water source protection.
8. Long-term goals include rejuvenating dying water sources and protecting their recharge areas. This goal can be accomplished by building knowledge and skills of stakeholders and documenting the multiple, interacting forcing factors impacting the hydrologic cycle to develop a long-term solution for drying lakes and spring declines in the region.

As an example, it had been assumed that planting trees was the ultimate solution to many water issues without considering the volume of water the tree would use. In some cases, looking beyond what has been done is necessary based on this study. As groundwater recharge areas are identified, policymakers may be able to identify critical areas to protect and ensure water sources continue to be protected in a changing climate.

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