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Identifying potential recharge areas of mountain springs through hydrogeological mapping

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Springs are the primary source of water for the people inhabiting in the hills and mountain regions of Nepal. Climate variability, climate change, land use change and management factors together with various human activities including haphazard infrastructure development like urbanization and road construction over the recharge area are responsible for drying up of springs in the hills and mountains, especially in the mid-hill region of Nepal. This study attempts to identify the potential recharge zones of the springs within the four catchments *viz.* Banlekh and Shikharpur of Baitadi and Doti districts, respectively in far-western Nepal, and the Khaste and Begnas of Kaski district in western Nepal through hydrogeological mapping. Hydrogeological Conceptual Model was adopted while identifying the potential recharge areas. We measured the orientation of the rock outcrops, their types, and discontinuities found around the possible recharge areas. We prepared a conceptual hydro-geological layout of the spring-sheds based on the collected data, and delineated the potential recharge areas. We found the potential recharge zone of the Banlekh Springs at hill slopes and bedding plane within the catchment. However, the recharge zone of the Shikharpur Springs was found on the top and beyond the catchment due to the presence of a number of sinkholes. Moreover, the recharge zone of the Thulopadhero Spring was found to be controlled by the orientation of the rocks and fractures found in the unconsolidated sediments within the catchment and beyond the ridge of the escarpment. The rock orientation within the Falekund-Saunepani-Lapsibot Catchment suggests that the potential recharge zone of the springs consists of unconsolidated sediments. The identified potential recharge areas, the observed rainfall, and the discharge data on springs indicated that the recharge areas were more influenced by the local geology.

Key words: Drying springs, geological setting, hydrogeological process, recharge zone and spring-shed.

Springs are the ultimate source of water for the people inhabiting in the hills and mountain regions of Nepal. Almost 80% of the people residing in these areas use springs as their primary source of water (Sharma *et al.*, 2016). It is often used for livestock feeding, irrigation for agricultural field etc *(Chapagain et al., 2019; Niraula et al., 2020).*While springs play vital role in maintaining water-flow, water balance in lakes & ponds, it equally contributes in the downstream water availability (Rosegrant *et al*., 2009). Besides, these are important resources to maintain land productivity, ecosystem health, and wetland biodiversity. Despite the availability of plenty of water resources (Chaulagain, 2011; WECS, 2011), most rural villages, towns and

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even some cities are currently experiencing water shortages (Chapagain, 2019; Sharma *et al*., 2016).

Crisis of fresh water resources is the major concern across the globe as there is increasing demand of water with growing population and less availability of water (Mekonnen & Hoekstra, 2016). Drying up of springs in the Hindu Kush–Himalayan region will create water shortage as a major environmental threat (Mukherji *et al*., 2015; Rasul, 2012; Scott *et al*., 2019). About 50 percent of the perennial springs running in the Indian Himalayan Region have faced two fates; either being dried up or has been converted into seasonal water sources (Tambe *et al*., 2020). About 73.2% of the springs are found to have decreased their flow while 12.2% springs have dried up over the past 10 years or more in the Thulokhola watershed of Nuwakot District, Nepal (Poudel & Duex, 2017). In the central Himalayas, while the water remains available for major duration of the year, water shortage usually occurs during dry periods ranging from March to May, sometimes even extending uptp mid-June (Merz *et al*. 2004). The springs within the Banlekh, Thulopadhero and Falekund-Saunepani-Lapsibot catchments are used for drinking water. The local people use the springs even for irrigation in Shikharpur. However, they face water insecurity during lean season due to diminishing discharge of the springs.

Climate variability, climate change, land use change and management factors together with various human activities including haphazard infrastructure development like urbanization and road construction over the recharge area are responsible for drying up of springs in the mid-hill region of Nepal (Adhikari *et al*., 2020; Chinnasamy *et al*., 2015). Some major concerns for sustainable water resource management are found to be population growth, agricultural intensification, land use change, deforestation, economic development, and impacts of climate change (Merz *et al*., 2003; Negi & Joshi, 2002; Vaidya, 2012).

The average annual mean temperature is projected to increase by 1.72^0 C on average over a long period of time while the number of rainy days is likely to decrease by 1% in the long run (MOFE, 2019). Thus, increase in average temperature, change in precipitation pattern and decrease in number of rainy days will impact upon infiltration process.

Current understanding on spring hydrogeological processes in the Himalayas is inadequate, occurrence of springs is poorly understood, and watershed management stemming from inadequate understanding would not solve water scarcity challenge (Shrestha *et al*., 2018; Tarafdar *et al*., 2019). Water source protection is one of the programs under watershed management to increase spring discharge (DSCWM, 2015). Conventional watershed management approach (ridge to valley) has been found ineffective to enhance spring discharge in many cases (Rijal, 2016). The recharge area of a spring may lie within a watershed or back side of a watershed or multiple watersheds depending upon the local geology (Shrestha *et al.*, 2018). Since the source of spring water is mainly determined by aquifer characteristics rather than surface topography, spring-shed is the potential recharge area of a spring and hence it differs from watershed (Shrestha *et al*., 2018; Tarafdar *et al*., 2019). Identification of recharge area is, thus, important for effective implementation of recharge intervention.

This study intends to assess the hydrogeological process of the springs through hydrogeological mapping and identify the potential recharge areas of the springs in the mountain landscape of Karnali and Gandaki River basins in western Nepal. The specific objective is to identify orientation of rocks and fractures in the catchments and to delineate potential recharge areas of the springs in the four different catchments (two each in the Karnali and Gandaki River Basins).

Study sites

The study was carried out within four catchment areas *viz*. the Banlekh and Shikharpur Catchments of Baitadi and Doti districts, respectively in far-western Nepal, and the Khaste and Begnas Catchments of Kaski District in western Nepal (Figure 1). Those four different sites were selected to capture the differences in lithology which would support to explain the relationship between lithology and recharge zone. Both the Banlekh and Shikharpur Catchments lie in the lower Seti Watershed under the Karnali River basin while the Thulopadhero and Falekund-Saunepani-Lapsibot Catchments lie in the Seti River sub-basin under the Gandaki River basin. All the three springs *viz*. Falekund, Saunepani, and Lapsibot lie within the Begnas catchment.

The study was carried out in 2018 and accomplished in 2022.

Thulopadhero catchment: The catchment of Thulopadhero Spring, a tributary of Khaste Lake of Pokhara-26 covers an area of 12.67 ha. The elevation ranges from 1009 m to 1137 m above the mean sea level (msl). The catchment is located between 84^0 02’ 50.47” – 84^0 03’ 11.70” E longitudes and 28^0 12’ 28.62” – 28^0 12’ 42.34” N latitudes, respectively. The spring is located at 1009m elevation. Thulopadhero Spring is the source of water for drinking and other household consumptions within the locality.

Falekund-Saunepani–Lapsibot catchment (Begnas_Rupa catchment): The catchment lies within Pokhara-31. It covers an area of 56.82 ha, and its elevation ranges from 924m to 1125 m above the msl. The catchment is located between 84^0 07’ 14.49” – 84^0 07’ 45.99” E longitudes and 28^0 10’ 48.18” – 28^0 11’ 20.01” N latitudes, respectively. There are three springs namely Falekund, Saunepani and Lapsibot lying almost parallel to one another at the elevations of 924 m, 948 m and 951 m, respectively, within the catchment area. The water from these springs is used for drinking and other household consumptions within the locality.

Shikarpur Catchment: This catchment has three springs *viz*. Relapani, Tallo Paharpani and Mathillo Paharpani. These springs are located at 2087 m, 2269 m and 2294 m above the msl, respectively. The catchment is located between $80^0$40’ 57.52” – 80^0 41’ 45.44” E longitudes and 29^0 29’ 10.55” – 29^0 29’ 35.50” N latitudes, respectively. The catchment covers an area of about 374 ha, and its altitudinal range varies from 1812 m to 2470 m above the msl. These springs are the source of water for drinking and other household consumptions as well as micro-irrigation within the locality.

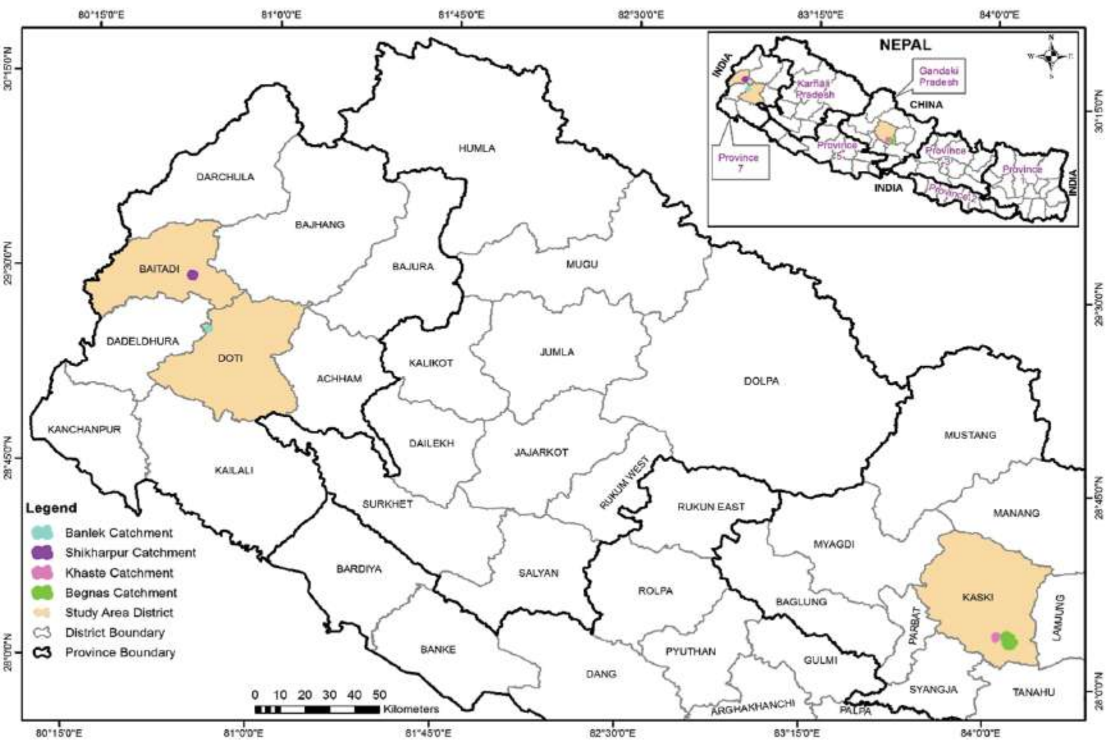

Figure 1. Location map showing the districts and catchment areas under the study (Source: Survey Department, Nepal, 1998/1999; modified by the researchers).

Banlekh catchment: There are four springs (Magarau Mul, Mallo Badekhola, Upallo Badekhola and Badekhola Noulo) lying linearly along the gorge at the elevations of 755m, 822 m, 832 m and 867 m above the msl, respectively. The catchment covers an area of about 174ha. The elevation ranges from 770 m to 1250 m above the msl. The catchment is located between 80^0 45' 50.94" – 80^0 46' 01.92" E longitudes and 29^0 17' 10.69" – 29^0 17' 24.06" N latitudes, respectively. The water from all these springs are used for drinking water supply and household consumption.

Material and methods

Hydrogeological mapping was adopted to delineate the potential recharge areas of all the selected springs in our study. Hydrogeological Approach is fundamentally based on the concept that local geological conditions control the sub-surface flow of water after rainfall infiltrates in the sub-surface. Hydrogeological mapping allows development of the conceptual model for site hydrology and identification of potential constraints on ground-water flow and protective zones (Jensen *et al*., 1997). Rock types and their orientations, openings and structural features of the rocks control the accumulation and the movement of ground water in the Himalayan regions (Shrestha *et al*., 2018). This study comprises three footsteps for delineating the potential recharge areas; (i) geological mapping of the study sites on the basis of field verification, (ii) conceptual hydrogeological layout of the spring-sheds, and (iii) identification and delineation of the potential recharge areas. A hydrogeological layout of a spring-shed is a geological cross-section that represent a spring and its connection to the surrounding geology viewed in 3-D (Dass *et al*., 2021; Shrestha *et al*., 2018).

We generated secondary data for hydrogeological mapping based on the existing geological maps produced by the Department of Mines and Geology, 2011 and the topographic features based on the digital database and topographic maps (1998 and 1999) published by the Survey Department. The data were modified based on the field observation made.

The geological traverses were performed covering the probable recharge areas of the selected springs to collect information on spring location, rock type, strike and dip values of rock outcrops and fractures (Shrestha *et al*., 2018) in the four selected catchments under this study. All the rock outcrops appeared within and nearby the catchments were taken into account during field observation. Brunton Compass was used to gather information on attitudes of rock and fractures. The geological information of Thulopadhero and Falekund-Saunepani-Lapsibot catchments are presented in Annex 1 and that of Shikharpur and Banlekh catchments are shown in Annex 2.

All the data collected during the transect walks were transferred to a Google file format (.kml) using the online converter www.earthpoint.us, and the interpolation and extrapolation of the rock outcrop data helped in producing the geological maps of the study area. An elevation profile (topography profile) of the catchment of each springs under study was generated using GoogleEarth and transferred to CorelDraw X7 Software to produce 2-D cross section for the individual spring-shed and subsequently 3-D conceptual hydro geological layout which displays the fracture trend, strike and dip of the rocks together with the location of the spring. The hydro geological lay out so generated was used to identify the area that supplies water to the aquifer that feeds the spring (Shrestha *et al*., 2018). The potential recharge area was then delineated based on the dips of the bedding plane and fractures plane and the type of rocks.

The rainfall and discharge of each spring in the Thulopadhero and Falekund-Saunepani-Lapsibot Catchments were measured from July 2018 to July 2019 so as to analyze the rainfall reaction on spring discharge. Daily rainfalls of the study catchment were recorded through installation of manual rain gauge while the weekly discharges of springs were measured by applying volumetric approach. The local citizens were trained and mobilized for the purpose of measurement. The rainfall and discharge of the respective springs within the Banlekh and Shikharpur Catchments were measured from August 2015 to December 2016 and October 2015 to December 2016, respectively, by the Building Climate Resilience of Watersheds in Mountain Ecoregions (BCRWME) Project under the Department of Soil Conservation and Watershed Management (DSCWM). The identified/delineated recharge area and the underlying geology were interpreted with respect to the rainfall and the discharge observed during one-year period.

Results

We generated the regional map (see Figure 2) of the study area based on the map produced by the Departments of Mines and Geology, 2010/2011, and later on prepared the local geological maps (see Figure 3) based on the regional map and the observation made during the transact walks. The

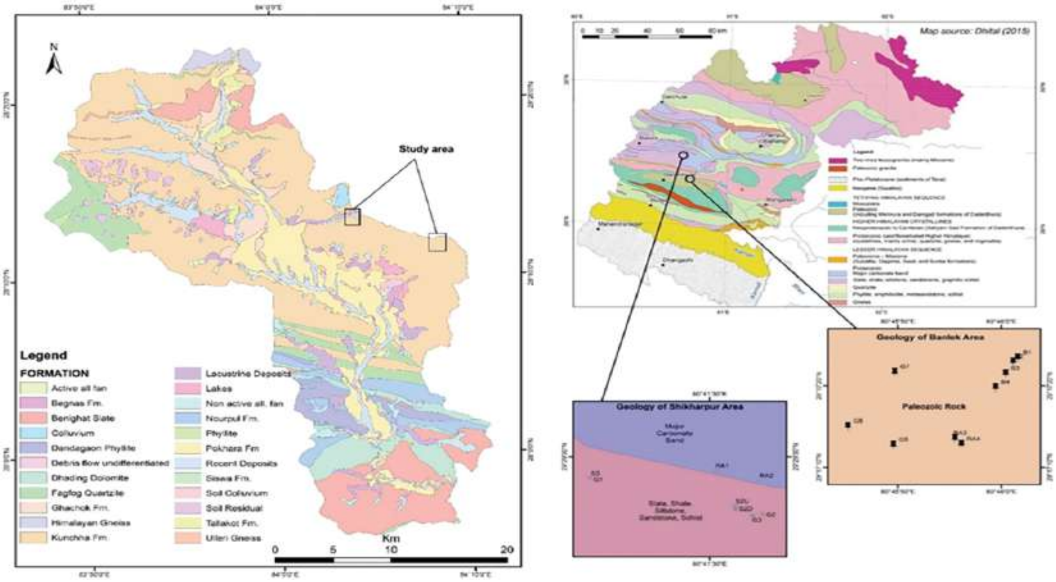

Figure 2: Regional geology of the study area; Thulopadhero, Falekund-Saunepani-Lapsibot (right) and Banlekh, Shikharpur (left) [Source: Department of Mines and Geology, Nepal, 2010/2011 and Dhital (2015)]

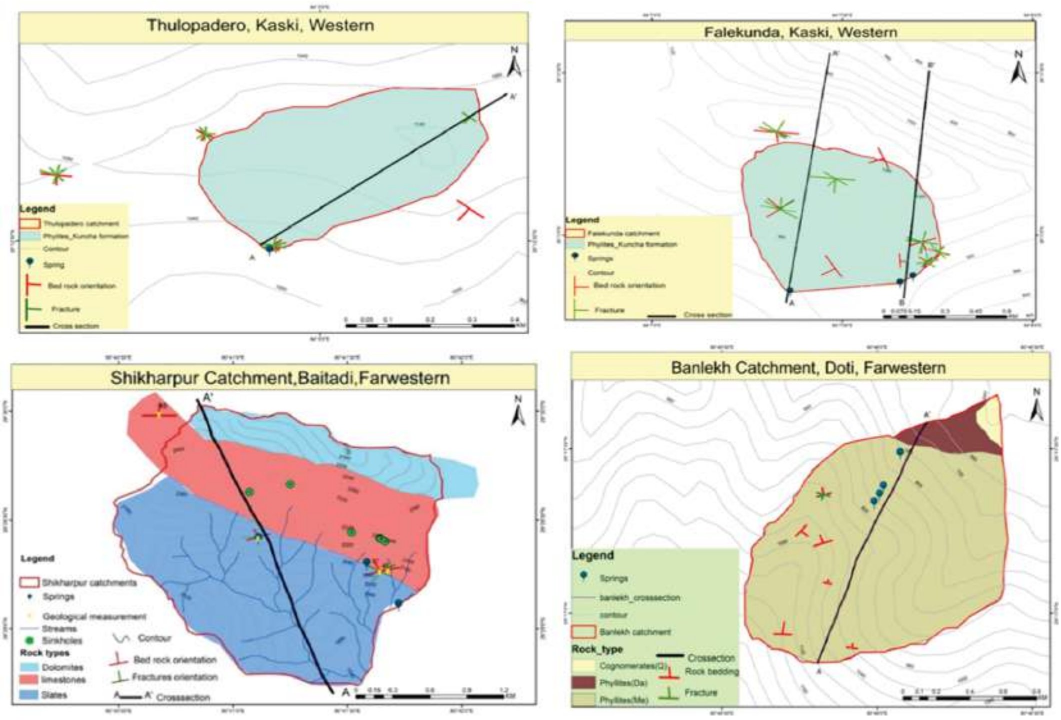

Figure 3: Local geology of the catchments within the study sites (Source: Geological maps prepared by the Department of Mines and Geology, Nepal, 2010/2011 and field observation)

local geological map so prepared included the attitudes of exposure rocks (strike, dip direction and dip amount), types of rocks around the catchment of spring, attitudes of fractures, and location of spring together with the geological cross section towards the spring.

The conceptual hydrogeological layouts indicating the potential recharge areas based on the observed data are depicted below in Figure 4a, 4b, and 4c for the Thulopadhero, Falekund, and Saunepani and Lapsibot springs respectively and those for the Shikharpur and Banlekh springs are displayed in Figure 5a and 5b, respectively. We used the hydrogeological layouts to identify the areas supplying water to the aquifers that feed the springs.

Delineation of the potential recharge areas

Based on the hydrogeological layouts, we identified and delineated the potential recharge areas of all the springs in the GoogleEarth Imagery, 2019. The hydrogeological layouts depicted the recharge areas based on the dipping and dip amounts of the bedding planes, presence of fractures and their dipping. The identified potential recharge areas of Thulopadhero, Falekund-Saunepani-Lapsibot, Banlekh and Shikharpur springs are showcased in Figures 6a, 6b, 6c and 6d, respectively.

Rainfall and discharge response

The observed seasonal rainfall data of the catchments and the discharge response of the springs are presented in Table 1 and the discharge response of the estimated potential recharge areas of the springs against the annual rainfall are depicted in Table 2. Similarly, the weekly rainfall and the weekly average discharge of the springs are showcased in Figure 7. The observed data indicated that the monsoon rainfall contributed to 81.6 %, 78.2 %, 69 %, and 70 % of the annual rainfall at Banlekh, Shikharpur, Thulopadhero and Falekund-Saunepani-Lapsibot Catchments, respectively.

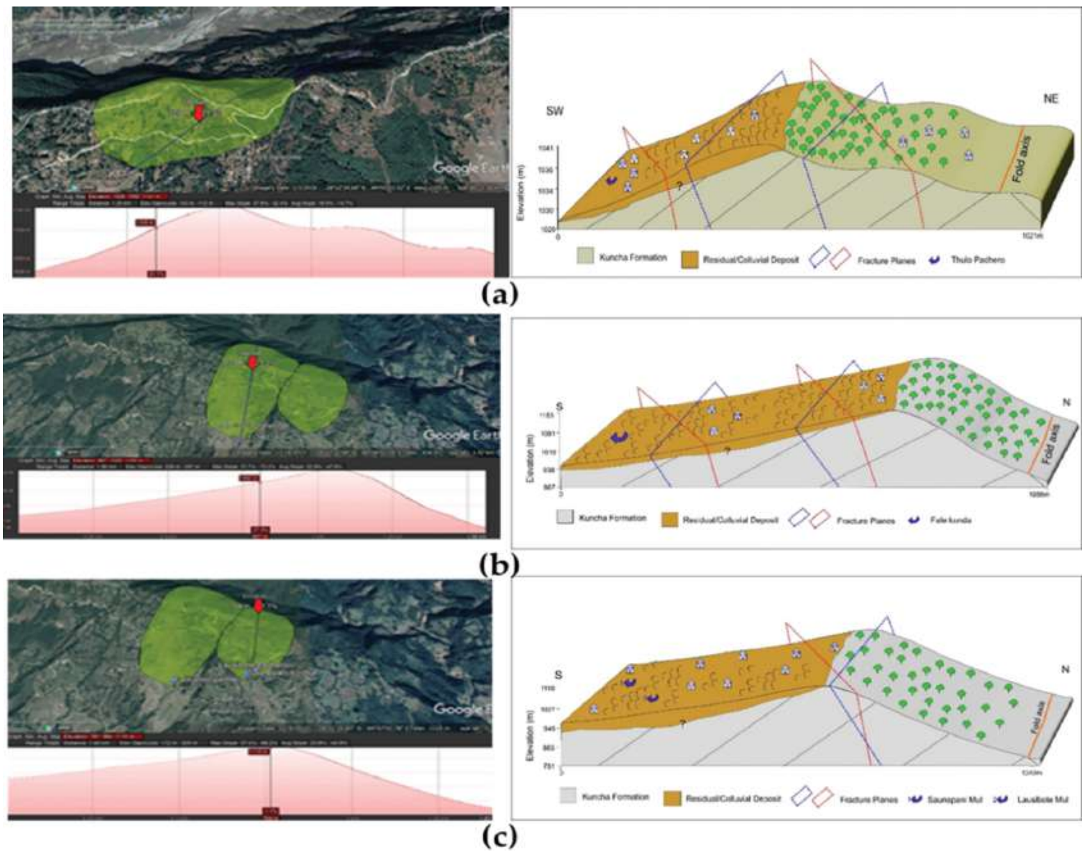

Figure 4: Conceptual hydrogeological layouts for- (a) Thulopadhero, (b) Falekund, and (c) Saunepani and Lapsibot springs [Source: GoogleEarth, 2019 and CorelDraw X7]

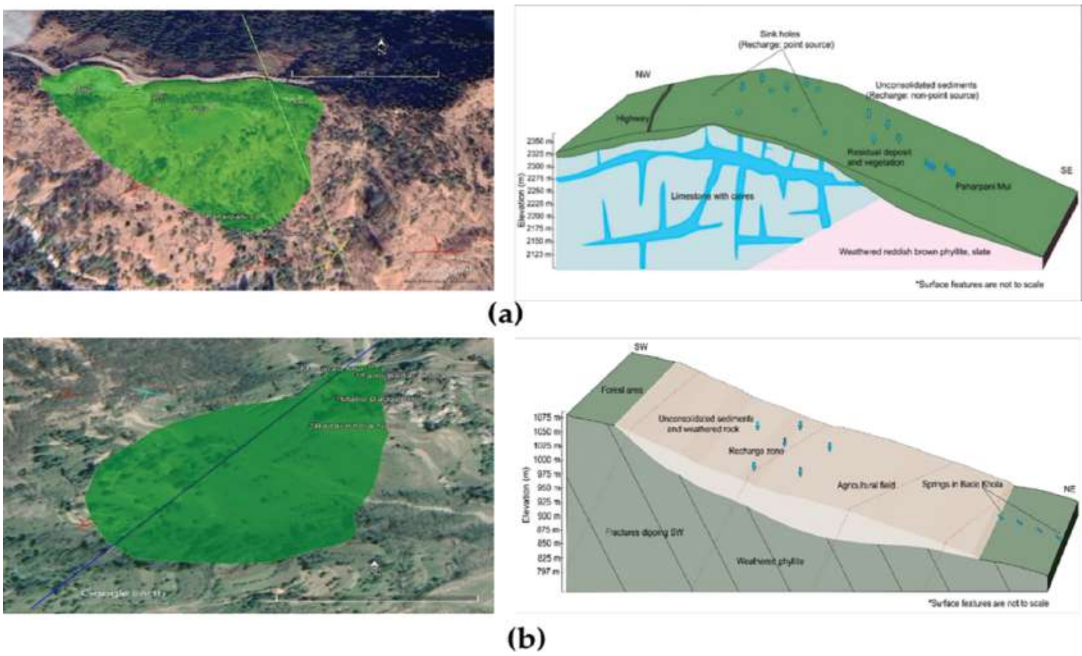

Figure 5: Conceptual hydrogeological layouts for- (a) Shikharpur and (b) Banlekh springs

[**Source: GoogleEarth, 2019 and CorelDraw X7**]

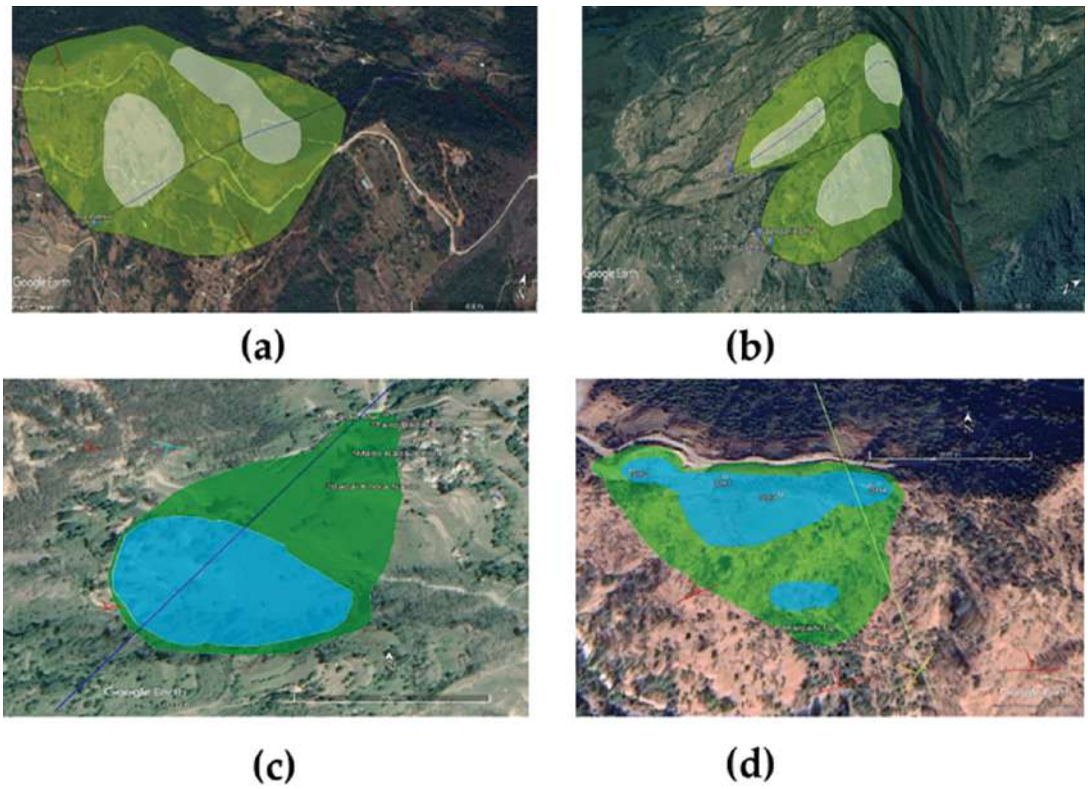

Figure 6: Potential recharge areas in the GoggleEarth imagery for the springs of- (a) Thulopadhero, (b) Falekund, Saunepani and Lapsibot, (c) Mangru Mul and (d) Paharpani [**Source: GoogleEarth 2019; modified by the researchers**]

Table1: Seasonal rainfall and discharge of the springs

S. N.	Season	Monsoon		Post monsoon		Winter		Pre-monsoon	
	Spring	**Rainfall (mm)**	**Discharge (LPS)**	**Rainfall (mm)**	**Discharge (LPS)**	**Rainfall (mm)**	**Discharge (LPS)**	**Rainfall (mm)**	**Discharge (LPS)**
1.	Thulopadhero	1986.93	0.54	149.78	0.36	186.37	0.11	562.44	0.03
2.	Falekund	2126.25	1.32	156.39	0.33	222.84	0.16	531.53	0.25
3.	Saunepani	2126.25	2.01	156.39	0.68	222.84	0.24	531.53	0.31
4.	Lapsibot	2126.25	1.30	156.39	0.40	222.84	0.05	531.53	0.23
5.	Banlekh	434	5.18 (LPM)	36.8	3.42 (LPM)	33	5.44 (LPM)	28	4.08 (LPM)
6.	Paharpani Tallo (Lower)	1621.6	7.18	51.4	2.27	50	0.88	348.6	0.60
7.	Paharpani Upallo (Upper)	1621.6	2.56	51.4	2.50	50	1.96	348.6	1.49

Note: LPS refers to liters per second while LPM refers to liters per minute

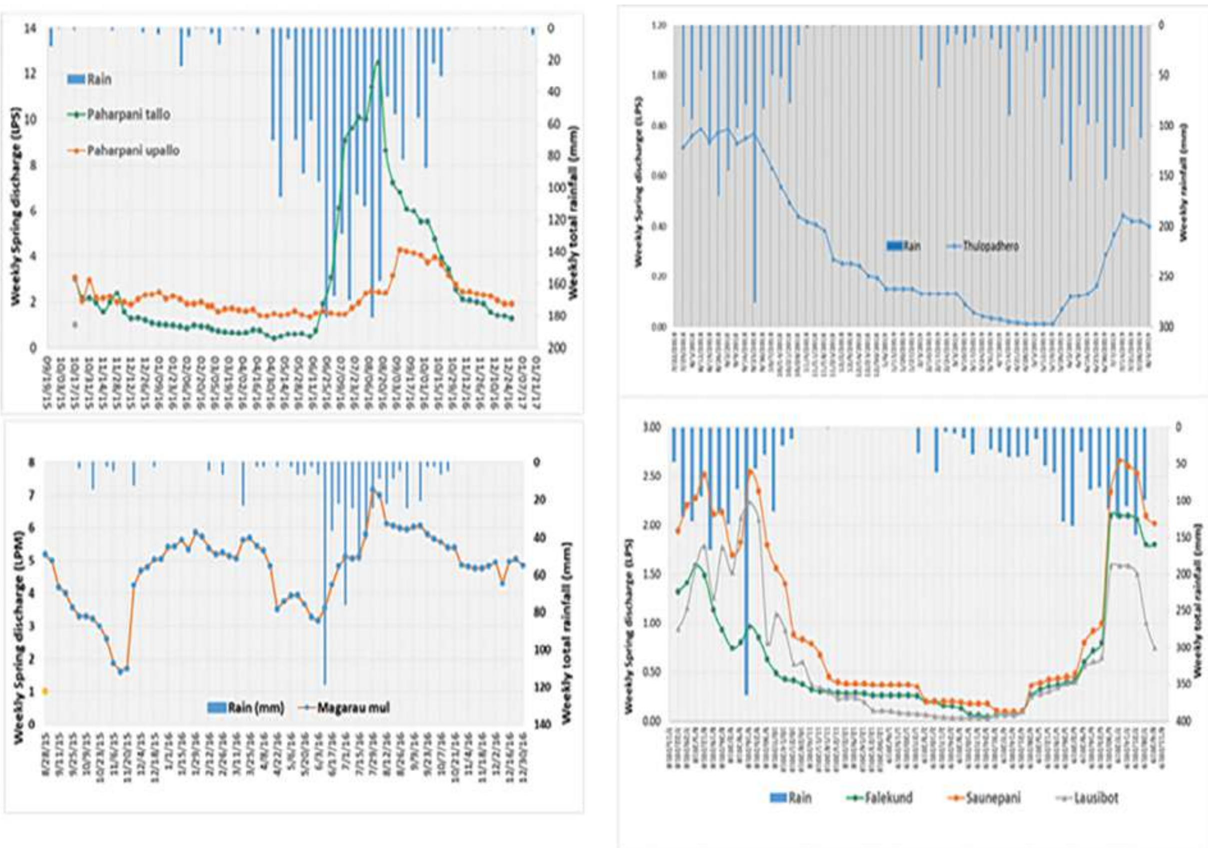

Figure 7. Weekly rainfall and discharge response of the selected springs

Table 2: Annual rainfall, annual average discharge and the estimated potential recharge area of the springs

Springs	Estimated potential recharge area (ha)	Annual average discharge (LPS)	Annual precipitation (mm)	Observations
Lower Paharpani Spring	3.12	2.93	2145.6	Higher discharge per unit recharge area
Upper Paharpani Spring	3.12	2.24	2145.6	Higher discharge per unit recharge area
Magarau Mul	3.73	0.08	531	Less rainfall and lower discharge
Thulopadhero	7.77	0.32	2852	More rainfall but lower discharge
Falekund	13.24	0.67	3037	More recharge area, More rainfall but lower discharge
Saunepani	8.20	1.04	3037.	More rainfall higher discharge per unit recharge area in comparison to Falekund
Lapsibot	8.20	0.65	3037	More rainfall but low discharge in comparison to Saunepani

Discussion

Thulopadhero and Falekund-Saunepani-Lapsibot catchment

Thulopadhero and Falekund-Saunepani-Lapsibot Catchments rest upon the Kuncha Formation (Dhital, 2015). It is composed of light grey-green to dark green phyllite, gritty phyllite and sandstone. It contains a monotonous non-calcareous sequence of alteration of phyllite, phyllitic quartzite and phyllitic grit stones. Fracture pattern is prominent with two or more than two sets. Loose unconsolidated materials and residual soil were found across the entire study area. Folded structures were seen at both regional and local scale. Attitude of foliations is towards SW and SE, which is due to one of the limbs of the regional anticline spreading from Majhthana to Bimirapani Village (Dhital, 2015). The dipping of the bedding planes in both the catchments is towards SW i.e. towards the springs. Therefore, the springs in this region are "depression springs" along with fractured rocks.

In the case of the Thulopadhero Spring, the bedding plane is slopped towards the spring, and is made up of weathered materials (Figure 6a). This geological setting shows that the potential recharge area is above the spring because of enhanced permeability caused by loose weathered sediments. Furthermore, the orientation of the fractures in the escarpment slope at the back of the catchment also supports the movement of water towards the spring.

Similarly, the fractures in the bedrock and unconsolidated sediments within the catchment above the Falekund Spring contribute favorably to its recharge. Therefore, the potential recharge zone in the case of the Falekund Spring lies above the spring and at the top of the catchment due to the existing fractures and dipping slope (Figure 6 b). The presence of unconsolidated sediments towards the dip slope and fractures at the ridge of the catchment is attributed to the spring recharge (Figure 6 b). Hence, the Saunepani and Lapsibot Springs possess the same recharge area on the same hill slope. Groundwater potential is relatively low in this type of litho-units, which is verified by the discharge data depicted in Table 2. However, we couldn't identify the individual recharge zones of the Saunepani and Lapsibot Springs. Topographically, both the springs seem to share the common recharge zone. Their hydrogeology study also could not recognize the separate recharge zones. They both must have different hydrogeological connectivity internally. Besides, the observation of the rock outcrop could not represent the geology underneath in this case. This is the limitation of hydrogeological mapping method. However if even more accurate result is required, environmental isotope analysis can be carried out. (Shrestha *et al*., 2018).

Banlekh and Shikarpur catchments

The general dipping trend of the bedding plane in the case of the Banlekh Catchment is towards north, and the outcrops are not well exposed. The springs in this region are “depression spring”. The identified potential recharge area of the Magarau Mul at the Banlekh Catchment is simply based on the concept of natural slope of the hill. The dominant rocks present in the catchment are phyllites (Dhital, 2015). Groundwater potential is relatively low in this type of litho-units, which is also verified by the discharge data presented in Table 2. Considering unconsolidated sediments at the top layer, the recharge area covers the hill slope and bedding planes to some extent (Figure 6 c).

The springs within the Shikharpur Catchment emerges out through reddish brown colluvial and residual deposit, and the dipping of the bedding plane is towards NW, opposite to the spring, thus making depression-cum-fracture spring. Geologically, the Shikharpur Area lies in the Lesser Himalayan Sequence while the Banlekh Area lies in the Tethyan Himalayan Sequence (Figure 2). The Proterozoic major carbonate band and mixed lithology of slate, shale, siltstone, sandstone, graphitic schist, Paleozoic rocks including Melmura and Damgad formations of Dadeldhura district are found in the Lesser Himalayan Sequence (Dhital, 2015). A number of sinkholes exist at the top and backwards of the Shikharpur Catchment, indicating a major carbonate band. The upper region consists of carbonate band with karstic feature, which makes the spring perennial and flow constantly throughout the year. Thus, the potential recharge area of the springs within the Shikharpur Catchment is at the top and also beyond the catchment (Figure 6 d). The identified recharge zones of the Banlekh and Shikharpur Springs are also supported by the study conducted through Isotopic Analysis (Matheswaran, 2019). The recharge area of the Banlekh Springs was found to be within the catchment while that of the Shikharpur Springs was noticed on the top and also beyond the catchment.

Rainfall and discharge response

The rainfall and discharge graph of the springs clearly demonstrated that the study region received 70 % to 81.6 % of the annual rainfall during monsoon season, and the discharge response of the springs is also relatively higher in monsoon. Karki *et al*. (2017) also discovered that about 80% of the annual precipitation was contributed by monsoonal precipitation while winter, pre-monsoon and post-monsoon precipitation covered only 3.5 %, 12.5 %, and 4.0 %, respectively. The observed data showed that the winter rainfall of the Falekund-Saunepami-Lapsibot Catchment is relatively higher (7.34 %) in comparison to that of the Thulopadhero Catchment (6.46 %), Shikharpur Catchment (2.41 %) and Banlekh Catchment (6.21 %), and thus contributing towards the discharge of springs in pre-monsoon period. The discharge trend of the springs within the Thulopadhero, Banlekh and Shikharpur Catchments was found to be decreasing during pre-monsoon in comparison to winter discharge. These findings reveal the contribution of winter rainfall towards the discharge of springs during pre-monsoon.

Size of the surface catchments, delineated potential recharge area, annual rainfall and discharge depicted varying discharge response of the springs (Table 1), mostly governed by the local geological conditions. The analysis on the weekly total rainfall and average discharge showed that there were varying response of the springs that could be due to different residence time and recharging characteristics in the catchment. The data reveal that spring discharge does not solely depend on the size of its catchment and rainfall but is also influenced by the local hydrogeology. Our study found that both the Paharpani Springs had highest annual average discharge in spite of their smallest identified potential recharge area in comparison to the other studied springs. This is due to the catchment features with carbonate band in which there are numbers of sinkholes which support for higher ground recharge. This result is also supported by Kulkarni *et al*. (2021) who claimed that the translation of rainfall into spring discharge is basically influenced by spatial variation in topography, geology and land use characteristics of a catchment.

Conclusion

This study explores the application of hydrogeological mapping to identify the potential recharge areas of the springs in mountain catchments. The study showed that each of the observed springs had a certain recharge area controlled by the orientation of rocks and associated discontinuities. The recharge areas of the springs at the backwards of the Shikharpur and Thulopadhero Catchments depicted that the recharge area of a spring could lie within or opposite side of its watershed depending upon the local geology. This underscores that if the primary objective is to enhance the discharge of any spring especially in the hills and mountains during lean season, a paradigm shift from practicing the conventional watershed management approach of the 'ridge to the valley' to the 'valley to valley' approach is urged. Furthermore, geology underneath the catchment controls the discharge capacity of a spring as observed in the Shikarpur Catchment. This study is expected to support the concerned policymakers in decision-making while planning climate-resilience-programs to address the issue of drying up of springs.

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Conflicts of Interest: The authors declare no conflict of interest.

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