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Status of springs in mountain watershed of western Nepal

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Abstract

The study, conducted in western hilly areas of Nepal, inventoried and mapped over 4,222 springs from five different watersheds. The study showed that more than 50% of the spring sources were found under natural conditions, i.e., open spring whereas 15% of them were of pond type. Similarly, the other 15% spring was recorded as a concrete structure or tank while 1% was determined to be a well. Attempts were made to identify if a change in water discharge from springs relates to rainfall patterns. The inter-annual variability analysis shows a significant fluctuation suggesting variation in water discharge across spring sources. The lowest amount of yearly rainfall received in the river basin is governed by decreasing water flow from the springs in the upper and mid-hills of Nepal. Besides, the intra-annual variation (i.e., seasonal and concentrative nature of rainfall only during monsoon) leads to shortage of drinking water and other domestic purposes (e.g., cooking, cleaning) during the dry months of the year. This study, based on the estimation of discharge flow in these springs, revealed that about 70% were decreasing and, in particular, the flow over the recent ten years decreased significantly.

Keywords: Climate change; Discharge; Rainfall; Spring; Watersheds

Highlights

- Springs are the primary source of domestic water supply in Mountain of Western Nepal.
- Many communities are experiencing increasing hardship in meeting their needs for freshwater in Western Nepal.

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- Springs in the Mountain Watershed of Western Nepal are in great threat.
- Around 70% springs have a decreasing trend of discharge.
- Restoration activities are urgent need to protect the springs in the Mountain Watershed.

1. Introduction

Freshwater resources are unevenly distributed on Earth (Yano *et al.*, 2015) and contribute only ~2.5% of the Earth's total water volume (Gleick, 1993; Shiklomanov, 1999; Priyantha Ranjan *et al.*, 2006). Approximately 68.9% of the freshwater is locked in the form of ice and permanent snow cover in mountainous regions, the Antarctic and Arctic regions, and 30.8% is stored in the form of groundwater (Gleick, 1993). About 97% of the groundwater resources are potentially available for human consumption and use, including agricultural sector, industries, and domestic and recreational users (Kibona *et al.*, 2009; Cassardo & Jones, 2011; Liu *et al.*, 2011). However, only a small fraction of the Earth's water is available for ecosystems and humans, i.e., less than 1% of all freshwater resources, and only 0.01% of all the water on Earth (Gleick, 1993; Shiklomanov, 1999). This implies that a total of around 2,120 km^3 of freshwater is available for human use and consumption (Cassardo & Jones, 2011).

In situ conservation of freshwater is greatly influenced by the distribution of water sources across the Earth's surface (Du Plessis, 2017). Human settlement and water resources are unevenly distributed across the Earth's surface as much as the water resources located far from human populations (Gleick, 1993). According to the World Business Council for Sustainable Development, the minimum basic water requirement for human health is 50 L per capita per day and the minimum amount of water required per capita for food is 400,000 L (Du Plessis, 2017). However, there is huge disparity on the consumptive uses of water among developed and developing countries. For example, developed nations like the USA consume eight times more for human consumption and four times higher per year for food production (Kibona *et al.*, 2009; Cassardo & Jones, 2011; Du Plessis, 2017). This fact clearly shows that water resources are distributed and utilized unevenly across the world, and most of the total freshwater is highly concentrated in specific regions, including North America, whereas regions like the Middle East and North Africa face a water deficit (Cassardo & Jones, 2011). In terms of water availability, Nepal is one of the rich countries in the world with 225 billion m^3 of water flow (WECS, 2011). There are over 6,000 rivers and rivulets of rain-fed and snow-fed origins with a total drainage area of 194,471 km^2, 45.7% of which lies in Nepal (NCVST, 2009; WECS, 2011). It is estimated that Nepal has a total renewable water resource of 237 km^3/year (225 km^3/year for surface sources and 12 km^3/year for groundwater sources) and per capita water availability for 2001 was 9,600 m^3/capita/year (WECS, 2011), which is very low as compared to other developing countries. There are many rivers, rivulets, brooks, streams, waterfalls, lakes, and small springs distributed throughout the country. From an economic growth perspective, rivers are the most important water resource for Nepal. It estimated that Nepal possesses about 2.27% of the total freshwater resources in the world (WECS, 2011). In terms of utilization of the water resource, only 15 billion m^3 water has been utilized for social and economic development in Nepal; the remaining water drains over the large Indo-Gangetic Plain (IGP) and ultimately drains down to the Bay of Bengal (WECS, 2011).

In Nepal, medium and small rivers are also utilized for different purposes, such as drinking water, irrigation, and hydropower development (Nepal *et al.*, 2019). Most of the drinking water supplies in the hill and mountain areas are through gravity flow system from natural springs, which represent the groundwater storage within the catchment, and form an important component of the Himalayan water budget (Andermann *et al.*, 2012). Villagers have been using these groundwater springs since time immemorial to meet their basic domestic needs, irrigation, and for livestock (Ghimire *et al.*, 2019). Spring sources form the backbone of Nepal's water supply in the middle mountain watersheds. However, in recent years, the water resource in the aquifers is depleting as a result of multiple anthropogenic activities and climate change factors (Tambe *et al.*, 2012). Anthropogenic activities like degradation of the catchments, land use change, and development of infrastructures such as road networks have disrupted the hillslope hydrology in the middle mountains of Nepal (Ghimire *et al.*, 2019), which has led to drying up of spring sources and the reduction of regular flow regimes, especially during the dry season (ICIMOD, 2015; Chapagain *et al.*, 2019; Ghimire *et al.*, 2019).

Springs are the major water sources in the high hills and mountains of Nepal Himalaya for drinking and other household uses (Gurung *et al.*, 2019b). Springs generally form in impermeable and sloping ground intersecting with ground water table and yield water during both rainy and non-rainy seasons and which is affected by rainfall and the recharge area characteristics (Negi & Joshi, 2004). Moreover, in context of the springs in Nepal Himalaya, they also depend upon the monsoon rainfall (Sharma *et al.*, 2016) and seem to be vulnerable (Gurung *et al.*, 2019a).

At present, water resources are severely stressed and particularly scarce in the middle mountain region of Nepal (Wester *et al.*, 2019). In many villages of the region, water shortage has been a growing barrier to local livelihoods and poverty alleviation. Activities like discharging domestic sewage and sludge without treatment, agricultural chemicals and solid wastes, and encroaching upon riverbanks for illegal extraction of riverbed materials have polluted the existing surface water (Gurung *et al.*, 2019b). Similarly, water availability has been worsening with increasing variability and uncertainty in seasonal and annual precipitation. Furthermore, the earthquake of 2015 disrupted the groundwater water table in the central Nepal Himalayas as villagers explained that many spring sources were dried up after the incident (Yadav, 2014). Along with the increasing population, water demand is increasing, and the water supply is challenged when the water availability remains the same or decreased at source. For the same reason, some economically active households have outmigrated to areas with adequate water supply. Only protecting and conserving spring sources combined with efficient use of water are options available to address the issue of water shortage.

The occurrence of groundwater is greatly influenced by the interaction of the climatic, geological, hydrological, physiographical, and ecological characteristics (Andermann *et al.*, 2012). For example, the alteration of physical characteristics of freshwater systems through infrastructure developments, e.g., road network, deforestation, over-extraction of river resources, greatly influences land use, wetland, hydrology, and geomorphology (Alcamo *et al.*, 2008; Du Plessis, 2017). In Nepal, research on groundwater is very limited and hence little known, both in the Terai plain or hilly mountain areas. Until recently, very little research work has been done to map spring sources in the middle mountain areas of Nepal. To address the issue related to water availability, water supply and distribution, having a longer-term impact database would be required inclusive of geology and structure, geomorphology and groundwater and hydrology. Generating knowledge on mapping of water resources and monitoring water flow and factors associated with change in water availability are prerequisites for effective management of scarce water resources. With due consideration of this issue, this research was designed to generate knowledge on mapping of groundwater spring sources using geospatial techniques in watersheds of western Nepal.

2. Materials and methods

2.1. Study area

This study was conducted across five different watersheds of Nepal Himalaya, namely, Jhimruk, Bogtan-Lagam Karnali, Rangun, Thuligad, and Middle Karnali watersheds located in different watersheds, i.e., Mahakali, Karnali, and Rapti (Figure 1). The Bogtan-Lagam Karnali and Middle Karnali are the smallest and largest watersheds covering 200 km^2 and 1,000 km^2, respectively. The altitude of the watersheds ranges between 300 m and 2,400 m above sea level. The drainage patterns of all the watersheds are dendritic. The watersheds stretch out in various degrees of slopes and topography. The climate of the study area is warm temperate with the mean annual temperature recorded between 7.7 °C and 21.9 °C in Jhimruk, 11.9 °C and 23.9 °C in Bogtan-Lagam Karnali, 12.7 °C and 24.4 °C in Rangun, 11.6 °C and 23.8 °C in Thuligad, and 3.9 °C and 22.4 °C in Middle Karnali and the average annual rainfall of 1,274 mm to 2,427 mm in Jhimruk, 1,558 mm to 1,856 mm in Bogtan-Lagam Karnali,

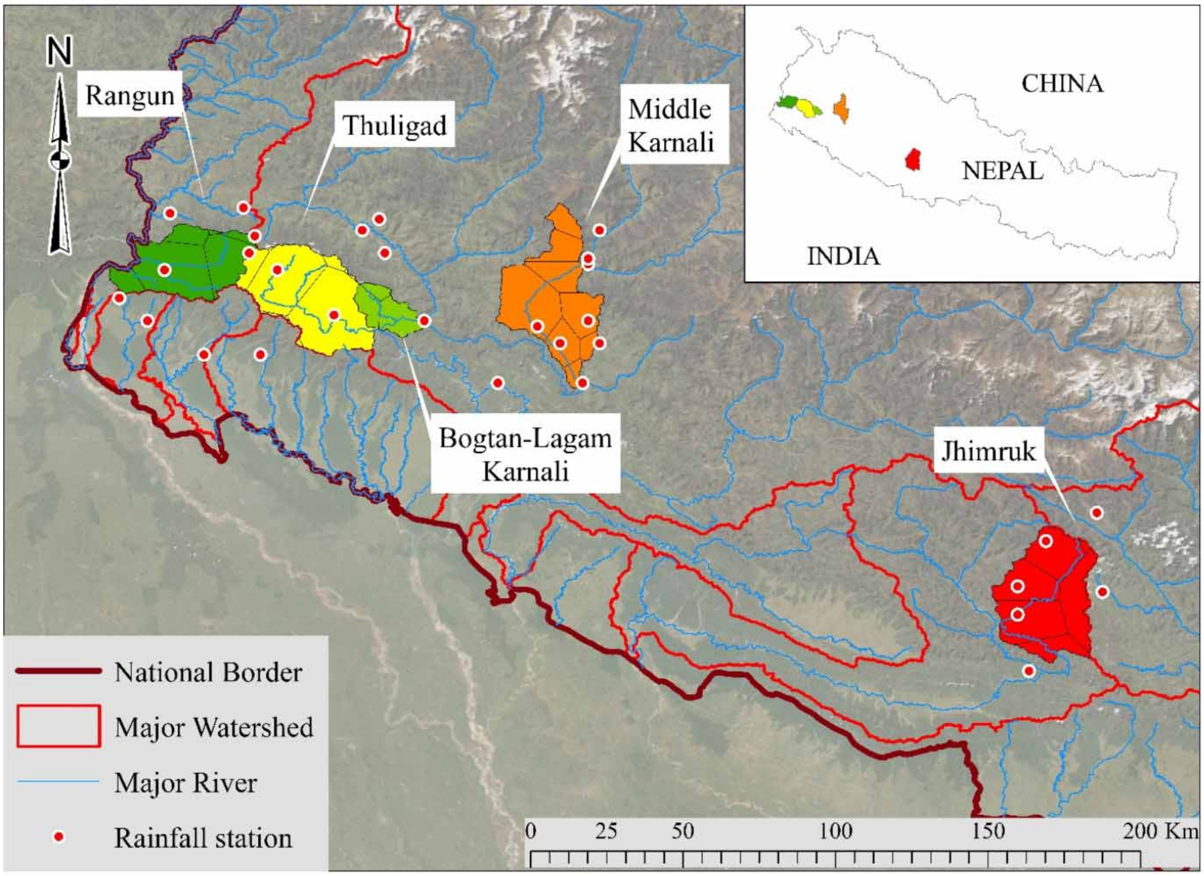

Fig. 1. Study area showing five selected watersheds. Weightages based on Thiessen polygon are used for evaluating basin-averaged rainfall.

1,631 mm to 2,024 mm in Rangun, 1,231 mm to 2,156 mm in Thuligad, and 1,160 mm to 1,840 mm in Middle Karnali (Karki *et al.*, 2016).

2.2. Data collection

In order to get the necessary data for the analysis we collected data from the study area. For the rainfall, daily rainfall data were collected from the Department of Hydrology and Meteorology (DHM) for the period of 1986 to 2015. We applied weightages based on Thiessen polygon in order to evaluate basin rainfall. The basin-averaged rainfall data were used to analyze the inter-annual variation. Similarly, using ArcGIS 10.1 (Esri, Redlands, CA, USA) and several satellite images, geological and topographical features and distributions of the rivers and streams were reviewed for the selected watershed areas. Land use changes, geological map, and on-site investigation were adopted to quantitatively and qualitatively describe the hydro-geological condition of the watershed area. Along with the available mapping technology we used manual mapping techniques based on the field observation for this preliminary study. Data collection coverage is made as far as possible where a field surveyor has access or can reach the area either by foot or other means of transportation.

All the spring sources (Figures 2–4) were mapped manually by the team of experts in the Bogtan-Lagam Karnali watershed. In addition, locally identified citizen scientists were oriented on data

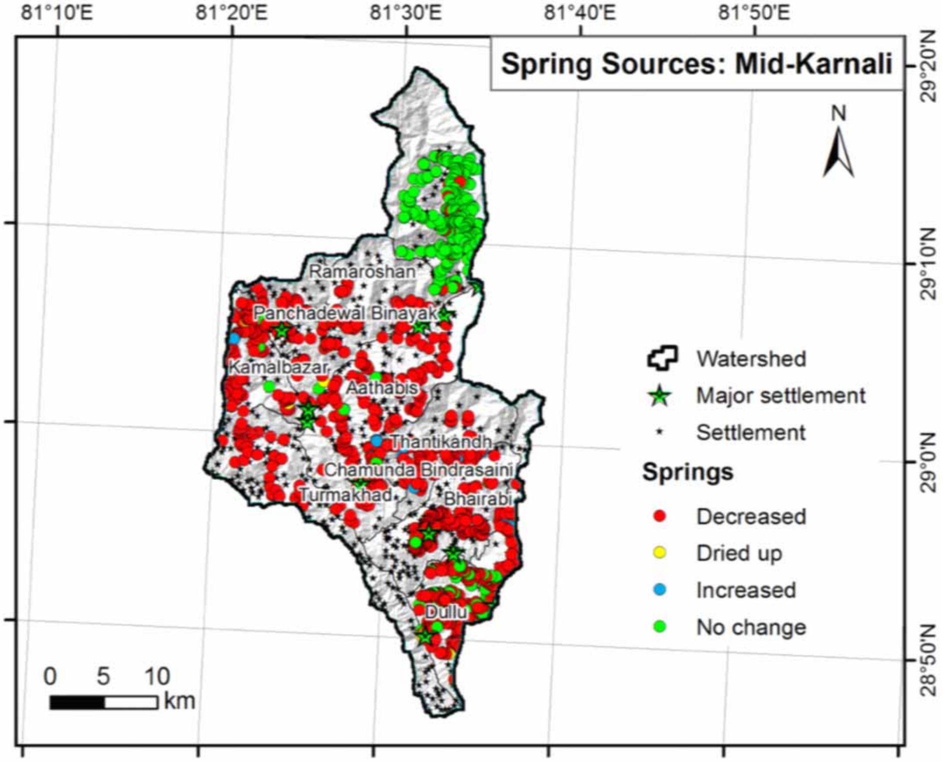

Fig. 2. Spring sources mapped in the Middle Karnali watershed.

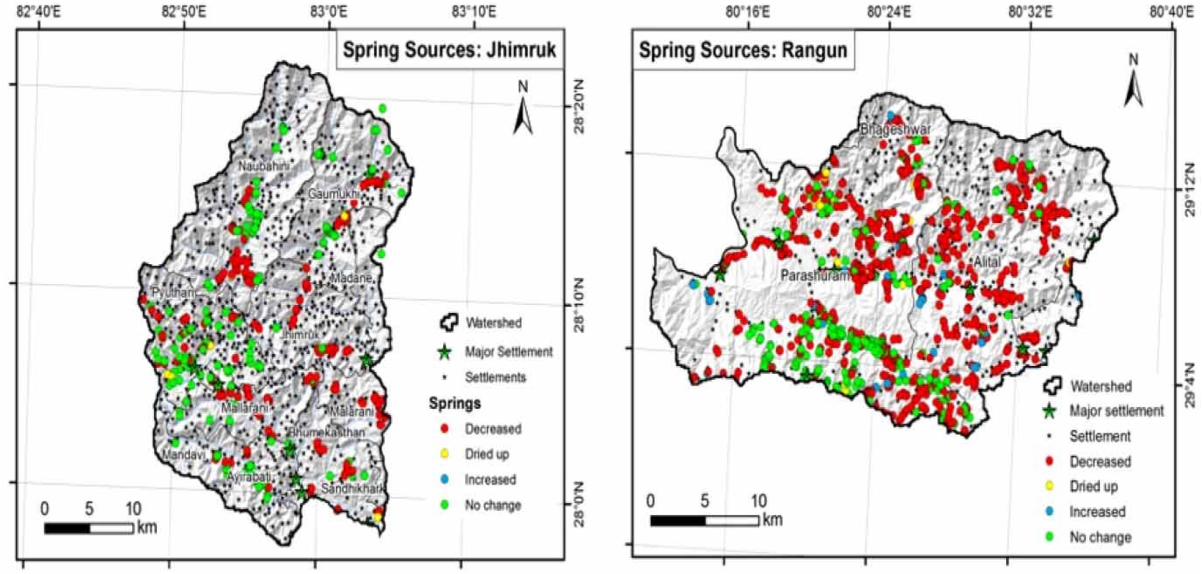

Fig. 3. Spring sources mapped in the Jhimruk and Rangun watersheds.

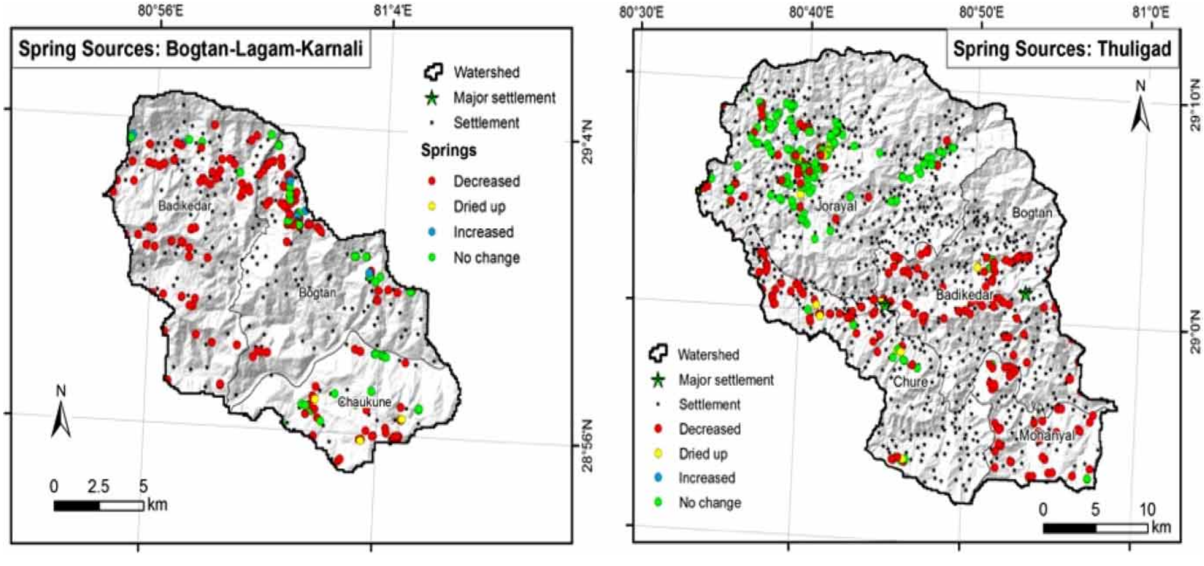

Fig. 4. Spring sources mapped in the Bogtan-Lagam Karnali and Thuligad watersheds.

collection for the remaining watersheds based on the experienced gained from the Bogtan-Lagam Karnali with hands-on training prior to deployment for data collection. The data were collected with a structured questionnaire uploaded in Kobo Toolbox (https://www.kobotoolbox.org/) using mobile application. Along with the mapping of spring sources, the discharge flow was estimated with two different methods: (1) bucket method and (2) surface flotation method. As the land use change also plays an important role in groundwater recharge, the information pertaining to land use change was carefully collected from all the watersheds.

A recall method was used for developing the inventory of the spring sources followed by on-site verification and discharge measurement. Also, the personal key informants, known as citizen scientists, monitored spring sources. Moreover, the comment about the time taken to fill a 20 L vessel 20 years ago, 10 years ago, and now from the springs and the measured data were compared with the locals' opinions for further validation of the research. All the location coordinates of the springs were recorded using GPS and further collected coordinates were then converted to ArcGIS shape files in the form of point features for further analysis.

3. Results and discussion

3.1. Types and distribution of springs

This study assessed the existing water availability, uses and its impacts on watershed hydrology in five respective watersheds. The primary focus of the study was to locate and map existing spring sources and their status in terms of water discharge, uses, and their discharge trend. A total number of 4,222 springs were spotted across five watersheds. The number of springs mapped in five watersheds are depicted in Table 1.

The rural mountain watersheds, especially during dry periods and low flow years, face acute shortage of water. People in all selected watersheds are facing the same problems. Water discharge in existing springs has been decreasing, some perennial springs have changed to seasonal, while the seasonal springs have dried up completely. A total number of 1,960 springs was mapped in the Middle Karnali watershed (Figure 2). The springs in these watersheds are gravitational fracture springs which are either perennial or seasonal in nature. Water discharge in the majority of the springs was found to be decreasing when compared with the flow of over 20 years ago. The water flow has decreased in approximately 71.67% of the springs. The water flow remains unchanged in 26.15% of the springs. In very few springs, water flow has increased. In 1.53% of the springs, water flow has increased as compared to previous years. Mapping revealed that 0.65% of the springs have dried up. Spring sources are mainly used for drinking and other domestic purposes, including cooking, washing clothes, and for livestock.

Figure 3 shows the springs mapped in Jhimruk and Rangun watersheds. A total number of 491 and 1,122 springs were spotted in Jhimruk and Rangun watersheds, respectively. Since the springs were mapped manually, the total number of springs mapped may not completely capture the springs available in the watershed. In both watersheds, the water discharge has decreased significantly. In Jhimruk, the water discharge has decreased by approximately 84.56%. Similarly, in Rangun, the water discharge has decreased by 72.59%. If this trend continues then the watershed will face acute shortage of water. It was found that in 3.44% of the springs in Rangun water discharge is increasing. The process of drying up of springs is also on the rise. For example, 3.78% of the spring sources have dried up in Jhimruk and 2.07% of the spring sources have dried up in Rangun.

Figure 4 shows the springs mapped in Thuligad and Bogtan-Lagam Karnali. A total of 343 springs was mapped in Thuligad and 213 springs in Bogtan-Lagam Karnali. Inhabitants of rural mountain villages in Bogtan-Lagam Karnali are primarily concerned about declining discharge and raised the issue of efforts needed for the protection of natural springs. Community survey and discharge measurement

Table 1. Distribution of spring numbers by watershed and rural municipality/municipality.

Watershed	Municipality (Urban/Rural)	Number
Jhimruk		493
	Bhumekasthan RM	27
	Malarani	19
	Ayirabati	34
	Gaumukhi	65
	Jhimruk	93
	Naubahini	89
	Pyuthan	100
	Madane	14
	Mallarani	52
Thuligad		434
	Chure	77
	Jorayal	190
	Badikedar	100
	Mohanyal	67
Boktan-Lagam Karnali		213
	Chaukune	53
	Badikedar	103
	Bogtan	57
Mid-Karnali		1,960
	Aathabis	198
	Kamalbazar	126
	ChamundaBindrasaini	249
	Turmakhad	48
	Thantikandh	164
	Dullu	541
	Naraharinath	375
	Panchadewal Binayak	178
	Bhairabi	81
Rangun		1,122
	Alital	364
	Jorayal	15
	Parashuram	743
Grand total		4,222

revealed a decrease in water discharge in 98.78% of the studied springs. In 61.22% of the springs, water flow is decreasing in Jhimruk watershed. In this watershed, approximately 3.05% of the springs were dried or the flow had permanently died.

As seen in Figure 5, the Jhimruk watershed in West Rapti basin received the highest average annual rainfall (i.e., 1,828 mm) and Middle Karnali in Karnali basin received the lowest average annual rainfall (i.e., 1,350 mm) among all other watersheds (ranging from 1,522 mm to 1,634 mm). Jhimruk watershed received the highest annual rainfall of 2,582 mm in 2009, whereas the lowest annual rainfall of 1,231 mm was in 1995, meaning even though the annual average value is comparatively high there are different years when rainfall was very low. Likewise, Thuligad Karnali watershed received maximum rainfall in the year 1990, around 2,225 mm, and the lowest rainfall was attributed to be

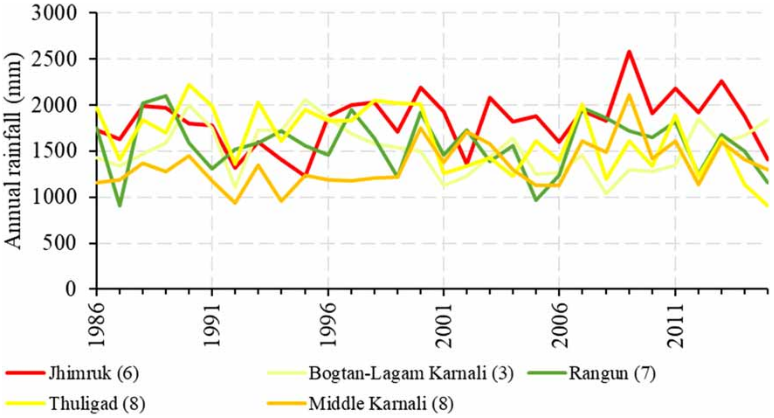

Fig. 5. Inter-annual variation of basin-averaged rainfall for selected watersheds for the period 1986–2015. Values in parentheses represent numbers of rainfall stations used.

907 mm in 2015. In general, the other three watersheds of Rangunin Mahakali basin, Middle Karnali, and Bogan-Lagam Karnali also showed similar significant annual fluctuations, where all the recorded rainfall during 1986 to 2015 ranged between 900 mm and 2,100 mm. Jhimruk and Middle Karnali revealed increasing tendency whereas the remaining three watersheds demonstrated decreasing tendency. Importantly, all the watersheds clearly showed significant amounts of annual fluctuations which could greatly affect the discharge of the springs.

The condition of the spring at source was analyzed as shown in Figure 6. About 56% of the springs are open springs, 15% are ponds, 15% are concrete tanks, 13% are stone spouts, and 1% wells. Generally, capturing water from an open spring is the most common and inexpensive process and has been used since ancient times in the mountain areas. However, in recent years, villagers have constructed concrete structures or tanks to store spring water.

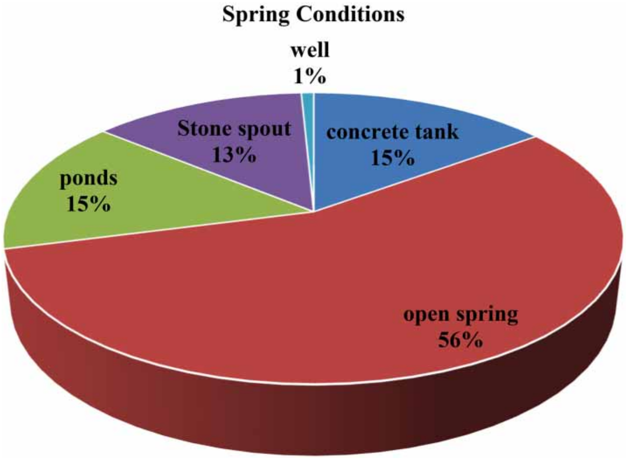

Fig. 6. Conditions of the mapping springs in the watersheds.

Springs are the only dependable and reliable source of water supply in the villages as not all villages have access to an improved water supply system. In the past, springs provided sufficient water for their basic requirements. Local people observed that the rainfall was not as much as it used to be two to three decades ago. However, in recent years, villagers have been facing a shortage of water. Their springs are not producing sufficient water for their day-to-day activities. The underlying causes of water scarcity include population pressure, land use changes, infrastructure development, increased water demand along with the introduction of modern technology, and the negative impacts of climate change (Sharma *et al*., 2016). Also, haphazard hill road construction, which is currently happening on every hill/mountain slope, has brought recurrent landslides and blocked many spring sources. As depicted in Figure 7, the flow from many springs has lessened. The findings revealed that the flow from approximately 70.07% springs has lessened. In some areas, permanent springs have transformed to seasonal while some 1.57% of the seasonal springs have dried up. The acute water shortage compels villagers to migrate from their villages.

Figure 8 shows the distribution of flow rate measured in the springs of the five studied watersheds. Most of the springs have a flow rate less than 2 L/s. Only a few springs have a flow rate higher than 18 L/s. According to the local people, the flow rate has changed significantly over the past 20 years. Citizen scientists confirmed with villagers the time taken to fill a 20 L vessel 20 years ago, 10 years ago and now from the springs. The community estimated 5.85 s to fill a 20 L capacity vessel 20 years ago, 7.67 s some 10 years ago, and 10.43 s at present. This clearly shows that flow rate has been decreasing in the springs. Since the springs are not sufficient to meet local demand, villagers are exploring other options to meet their water demand. Some of the initiatives that villagers are employing include piped water from distant spring sources, digging wells to tap the groundwater, and harvesting rainwater. However, digging a well in the mountain is a challenging task. In some areas the problem of water has become so acute that people use turbid river water to meet their water needs. For example, some villages near to the Karnali River do not have access to tap water and springs, and thus villagers rely entirely on Karnali River to fulfill their water needs.

Table 2 shows the distance between the spring sources and the nearest households in the watersheds. In Middle Karnali and Thuligad, 51.83% and 36.17% of the springs are located within 100 m of the settlements, respectively. In Jhimruk, Bogtan-Lagam Karnali, and Rangun, 29.01%, 12.67%, and 43.04% of the springs are located at a distance of 100–500 m from the settlement, respectively.

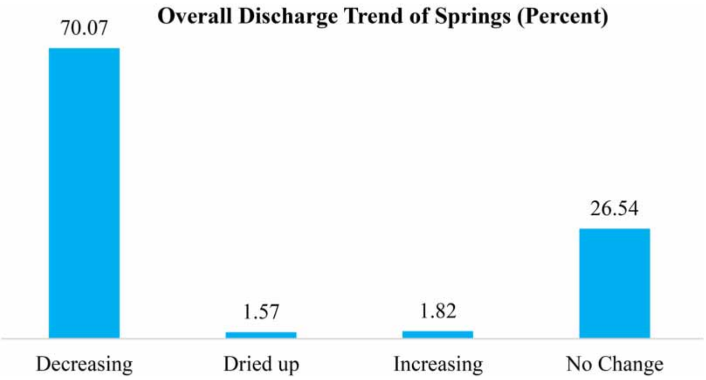

Fig. 7. Trends of springs in five watersheds of western Nepal.

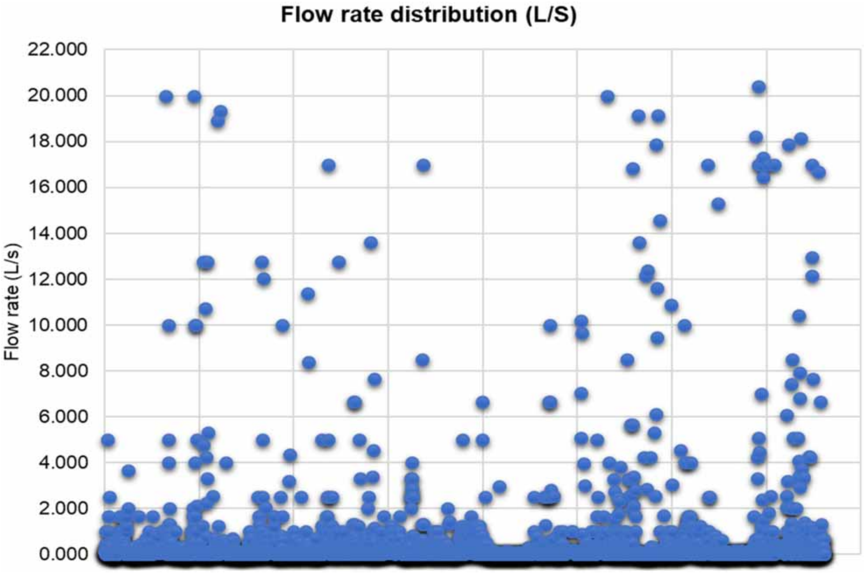

Fig. 8. Distribution of measured flow in the springs of five watersheds.

Table 2. Distance between the spring source and the nearest household.

Distance between the spring source and the nearest household (m)	Number of spring sources (%)				
	Jhimruk	Thuligad	Bogtan-Lagam	Middle Karnali	Rangun
<100	15.01	36.17	5.63	51.83	14.88
100–500	29.01	23.04	12.67	28.92	43.04
500–1,000	12.58	12.67	10.32	9.18	11.76
1,000–2,000	15.62	13.13	11.26	4.54	9.98
2,000–5,000	10.95	12.21	2.34	4.54	5.16

Figure 9 shows the distance between the spring source and the nearest settlements in the five respective watersheds. Generally, the natural springs in the mid-hills of Nepal are found at multiple sites around the hill slope (Sharma *et al.*, 2016). People usually establish their settlement where they have easy access to water sources. The finding also revealed that the majority of the springs are within 100 m distance from the settlement. However, in some parts of the mid-hills, people rely on a distant water source as well with 5% of the settlement relying on a distant source (>2,000 m). In some villages, drinking water is brought from a 10 to 15 km distance.

Although Nepal is a small country, it has tremendous geographic diversity. It rises from as low as 50 m elevation in the Terai to the highest point on Earth, the summit of Mt. Everest, at 8,848 meters, all within a distance of about 150 km. Such altitudinal fluctuation results in climatic conditions ranging from sub-tropical to Arctic. Figure 10 shows the number of springs mapped according to the elevation. The study revealed that approximately 51% of the springs are located at an elevation of 1,000–1,500 m. 22% of the springs are located at the elevation of 500–1,000 m. Very few springs

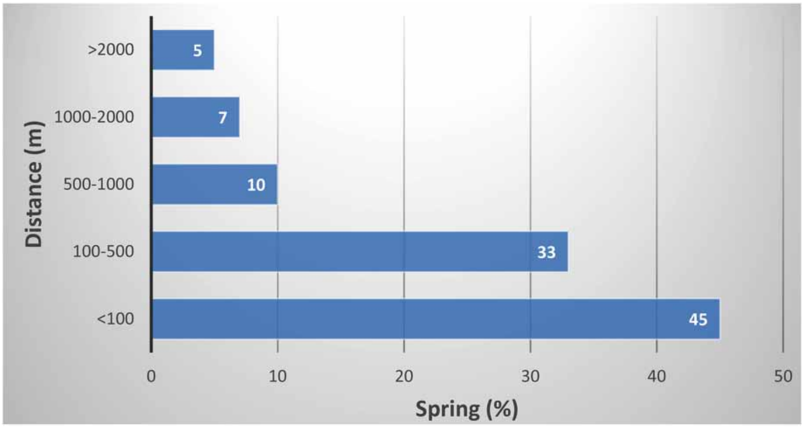

Fig. 9. Distance between the spring source and the settlement.

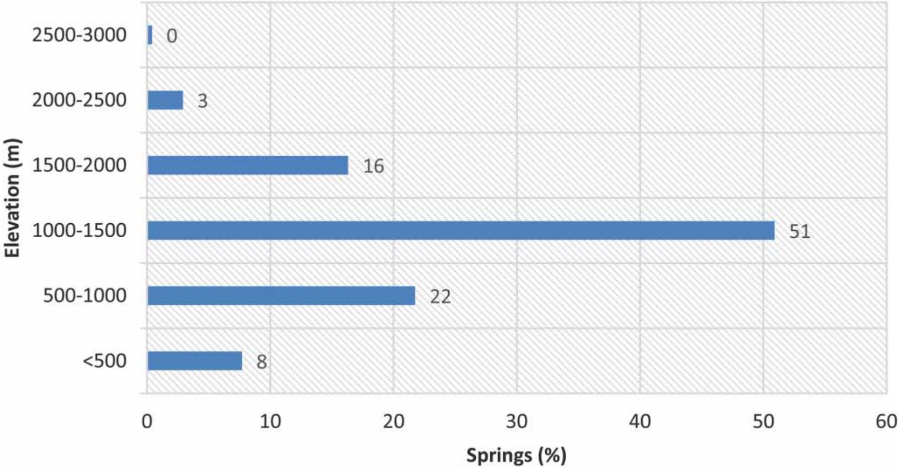

Fig. 10. Number of springs mapped according to elevation.

are located at the elevation of 2,000–2,500 m. The occurrence of springs is influenced by the rainfall pattern, intensity and infiltration rate. Rainfall pattern across Nepal is monsoon dominated and almost 80% of annual rainfall occurs during four months from June to September (Talchabhadel *et al.*, 2018). Shortage of water for household and agricultural uses across the study areas is acute during the non-monsoon period (meaning winter and spring). Harvesting of rainwater is an efficient technique to mitigate water shortage and meet the water demands of people. In the highlands, people also harvest snow and use the melt water for livestock and irrigation (Panthi *et al.*, 2019). Rainwater harvest could be either done at household level by collecting rainwater in different sizes of tanks or containers, or at community level by constructing community ponds or large depressions. Large depressions or ponds may help recharge the groundwater and provide a supply to natural springs.

Springs have been used by hilly and mountainous communities since time immemorial to meet the water needs of households, livestock, and irrigation. Natural springs make a major contribution to survival in the mid-hills of Nepal, especially in the long dry season. However, Nepal's freshwater resource is unevenly distributed across the country (Gurung *et al.*, 2019b). In addition, the availability of water for human consumption depends on the management of naturally available water. Year-to-year variation of total rainfall clearly indicates the fluctuation of these spring sources over time.

4. Conclusions

The study mapped a total number of 4,222 springs in Jhimruk, Rangun, Thuligad, Bogtan-Lagam Karnali, and Middle Karnali. About 56% of the spring sources was found in natural conditions, i.e., open spring. 15% of the spring source is ponds. 15% of the spring source is directly collected into concrete structures or tanks. Only 1% of the spring source is wells. As discussed earlier, water resources are becoming increasingly scare in the mid-west and far-west regions of Nepal. The shortage of water for drinking and other domestic purposes, especially during the dry periods, is of particular concern, but not for the monsoon season. In 70.07% of the springs, water flow is decreasing. According to the local people, the water flow has decreased significantly as compared to 10 years ago, and about 1.57% of the spring sources have dried up in the watersheds. The decreasing tendency of rainfall amount complemented people's perceptions and, most importantly, the significant year-to-year variation of rainfall affects the spring sources every year at a different severity. Besides the variation of rainfall, other potential factors like excessive unplanned road construction, vanishing of traditional ponds, lakes and wallows, tectonic movement and concreting and piping of sources also contributed to the drying springs (Gurung *et al.*, 2019a). Despite the rapid drying of springs the study found that that in some parts, villager's access spring water without implementation of adequate protection measures. However, if the situation remains the same, acute water crises will be prevalent in the near future in the mid-hills of Nepal.

In most of the areas the problem of water scarcity has become so acute that people have already migrated from their villages. If the water problem remains the same then more people will migrate from their original home villages (Gurung *et al.*, 2019b). In order to prevent this mass exodus from the villages, as well as to improve their water access, the current water resources management strategy must be reviewed at watershed scale. Based on the current findings the following future activities are recommended:

- New research needed to fully understand the science of the springs, which includes geohydrology, structural geology, and socioeconomic analysis for the better understanding of the demand of supply of water resources of particular watersheds in response to climate change.
- Immediate need of a watershed-level springs' restoration program with a participatory approach focusing on local communities, local government and academia, NGO and other stakeholders for the sustainability and upscale of good practices.
- Building capacity of local communities, local governments, and other stakeholders for understanding the multiple values of springs and protection of watersheds.
- Local government and communities should consider the values of watersheds before construction of any liner infrastructure.
- The need to develop and mainstream the watershed management plan at local developmental government plan.
- Traditional lakes, ponds, and wallows are great ecological services for rechanging the downstream springs, and so on. Therefore, protection of such lakes, ponds, and wallows is very crucial.
- Rainwater harvest at household and community level.
- Dissemination of the knowledge though local media, etc.

The research findings will be useful to inform and develop inclusive water supply plans, highlights the need for spring source protection and the promotion of multiple use technology to address the pressures on community access to water as a result of the decreased availability of water for domestic and livelihood purposes.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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