Depleting spring sources in the Himalaya: Environmental drivers or just perception?

A case study of Rangun Khola Watershed

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CONTENTS

ABSTRACT

Natural springs are the lifelines for human survival. Yet, declining flows and drying spring sources are a critical challenge faced by rural communities across the Himalayas. Deteriorating spring sources in the eastern and western Himalayas are evident, however, the status of spring sources is poorly understood in western Nepal. A trans-disciplinary assessment of social and political context is the combined package required for a holistic picture for sustainable water resources management. This study assessed the status, drivers of changes, and challenges for spring resources in the Rangun Khola watershed, far western Nepal. Spring sources mapping of 1,122 springs within the watershed documented the status and spring flow trends. Land Use Land Cover change trajectory analysis, climate trend and indices analysis along with household perception, development, and political scenario analysis were the supplementary assessment procedures applied for understanding the impact and implication of different drivers of change on spring sources.

Spring source mapping, based on flow measurement, indicated that most sixth and below magnitude springs are a prominent source of drinking water for the communities in Rangun Khola watershed. The flow trend assessment revealed that almost 76% of springs are showing a continuous declining flow trend with 2% already dried up. In the watershed communities, almost 82% of households perceived reduction in water resource availability over the past 10 years or more and attributed those disturbing developments to climate change and human activities. Gradual fragmentation of land and deforestation of 50 km^2 between 1990-2018to create agricultural land and expand urban areas has seriously impacted natural spring flows in Rangun Khola watershed. Even though a 30 m by 30 m LULC map assessment did not reveal any significant association with changing spring discharge, the micro landscape assessment of immediate spring surroundings revealed that undisturbed vegetation is supportive of spring flow maintenance. Similarly, local climate data assessment revealed that temperature is significantly increasing while precipitation patterns are showing alteration in form of increasing frequency of localized high-intensity rainfall events. This local climate variability is concurrent with drying spring sources and consistent with the local community's perceived local manifestation of microclimatic changes and its implication on spring sources. Changing global and microclimate and local vegetation cover is one of the leading natural stressors for spring sources in the Himalayas. Moreover, the growing population and haphazard rural road expansion are overexploiting and interfering with spring resources in the

Himalayas. Changing spring flow dynamic and its implication on local livelihood and society are evident in the communities; however, government and local households are lagging in taking direct actions to mitigate the problem.

The study documenting the status, characteristics, stressors, and challenges for spring resources in Rangun Khola watershed informs future research and sustainable spring watershed planning and management interventions. The research outcome is expected to be potentially beneficial for spring source conservation, spring watershed protection, and a crucial component for integrated water resource management and planning in appropriate watersheds.

DECLARATION

I, Anju Pandit certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: 

Date: 21st October 2021

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LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BCTS	Brahmin Chhetri Thakuri Sanyasi
BOD	Biological Oxygen Demand
CBS	Central Bureau of Statistics
CC	Climate Change
CO2	Carbon Dioxide
DHM	Department of Hydro Meteorology
DO	Dissolved Oxygen
Esri	Environmental Systems Research Institute
ET	Evapotranspiration
FGD	Focus Group Discussion
GIS	Geographic Information System
GPS	Global Positioning System
HH	Household
ICIMOD	International Centre for Integrated Mountain Development
KII	Key Informant Interview
LULC	Land Use Land Cover
MoPE	Ministry of Population and Environment
PRA	Participatory Rural Appraisal
USAID	United States Agency for International Development
WECS	Water and Energy Commission Secretariat
WHO	World Health Organization

I. INTRODUCTION

1.1 Background

Water, one of the vital components of the environment necessary for human and ecosystem survival, is distributed widely in diverse forms in the earth's natural ecosystems (Chapagain, Ghimire & Shrestha 2019). One of the world's greatest freshwater resources, the snow and glacier-fed rivers flowing from the Himalayas, provide water to more than 1.4 billion people living in India, Bangladesh, Bhutan, and Nepal, and are a lifeline for the Hindu Kush Himalayan region (ICIMOD 2009; Immerzeel, Van Beek & Bierkens 2010).

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Figure 1: Hindu Kush Himalayan region, headwaters of the 10 major river basins (Molden & Sharma 2013).

However, unlike human populations of the valleys, plains and great river basins below, many upstream mountain communities are dependent on natural springs to meet household and agricultural demand (Chapagain, Ghimire & Shrestha 2019). Hence, natural discharge points of the aquifer (Kresic 2010) are a crucial source of water for drinking and sanitation for mountain communities in the middle watershed areas (Negi & Joshi 2002). Spring water, serving over 40 million people in the Himalayas (Mahamuni & Kulkarni 2012), occupies a significant portion of the Himalayan water budget (Andermann et al. 2012; Bookhagen & Burbank 2010). In Nepal, the contribution of fissured groundwater aquifers to the mountain watershed is significantly higher than the water runoff from the higher-altitude snow fields and glaciers of the Himalayas (Andermann et al. 2012). Springs are not only the instrument for water demand fulfilment, they are essential for biodiversity and are considered an integral part of cultural and spiritual belief in mountain communities (Tambe et al. 2012). Thus, freshwater springs have tremendous ecological and societal significance in the mountainous regions of Himalayas and should receive the highest priority for research and conservation actions aiming for sustainability. However, as with many other communities of the world, water scarcity in terms of quality as well as quantity is one of the major challenges faced by mountain communities in the middle watershed areas of the Himalayas (Wiegandt 2008; Martin et al. 2013).

The mountain springs flowing under gravity are mostly fed by precipitation (Sharma et al. 2016) and discharge from the unconfined aquifer (Tambe et al. 2012). Therefore, springs are strongly influenced by seasonal changes in precipitation (Fiorillo 2009), land use, vegetation cover (Valdiya & Bartarya 1989), soil characteristic, and geomorphology of the recharge zone (Negi & Joshi 2004). Recent research on sustainability of springs in Himalaya have reported that the synergetic effect of multiple anthropogenic activities, together with biophysical and social factors, have caused changes in flow dynamic of water resources in mountain aquifers (ICIMOD 2015; Dass et al. 2021). Among the range of drivers of these changes are haphazard infrastructure development and associated Land Use Land Cover (LULC) changes which are leading components disturbing the hill slope hydrology and contributing to catchment degradation in the fragile mountain watersheds (MoPE 2017; Reisman, Deonarain & Basnyat 2017). Changing geomorphology triggered by earthquake events is correspondingly imposing negative pressure on the spring sources in the mountain areas (Ghimire, Chapagain & Shrestha 2019). Moreover, a number of authors have noted climate change and vulnerability to influence are adding to the complexity of changing flow regime of these lifelines of the mountains (Negi & Joshi 1996, 2002; Immerzeel, Van Beek & Bierkens 2010; MoPE 2017; Nepal et al. 2019; Sharma et al. 2019). The accumulated impacts of the these dynamic factors in a mountain environment, may result in a temporary alteration in flow regime, which may change the quantity of flow as well as the timing, duration, and seasonal pattern of ecologically important flow events (Agarwal et al. 2012; Mahamuni & Kulkarni 2012; Tambe et al. 2012) or may even cause a natural spring to permanently dry up (Agarwal, Agrawal & Nema 2014).

The hydrological system is an example of interconnected biophysical and social processes, including climate variability, water use, and infrastructure and land cover, which demand an interdisciplinary approach to study rather than from a science perspective only (Vogel et al. 2015). Understanding biophysical setup along with changing socio-political context from both a science and societal perspective is vital to address the issue of water resource management in rural mountains (Poudel & Duex 2017). Researches in the eastern and western Himalayas have helped to clarify the present status and implication of changing natural spring dynamics (Negi & Joshi 1996; Negi & Joshi 2002; Negi, Thakur & Mishra 2007; Poudel & Duex 2017 ; Gurung et al. 2019;Adhikari et al. 2021;). These studies have highlighted the distribution, hydrology, and changed dynamics of springs in localised mountains in eastern and central Nepal (Poudel & Duex 2017; Chapagain, Ghimire & Shrestha 2019; Ghimire, Chapagain & Shrestha 2019; Silwal et al. 2020). Studies in the Indian Himalayas, and the central and eastern Nepal Himalayas have reported declining spring flow in the mountain areas, which they attributed to the cumulative effects of changing climate variability (e.g., significantly increasing temperature, altered precipitation patterns) with associated physical and social factors of environmental change (ICIMOD 2009, 2015). Overall, research has increasingly focussed on determining the causes and consequences of declining water flows and drying spring sources in mountain pockets, which is indicative of the importance and urgency of gaining a better understanding of this issue (Negi, 2002; Tambe et al. 2012; Agarwal, Agrawal & Nema 2014).

According to the Water and Energy Commission Secretariat of Nepal (WECS), natural spring status documentation is the basis of future research and development of water management strategy for sustainable water resource management in the region (WECS 2011). However, there is a gap in current understanding of spring dynamics in some pockets of Himalaya, particularly in western Nepal. Therefore, knowledge is inadequate to support a holistic picture for sustainable water resources management in these regions (Alford 1992; Bruijnzeel & Bremmer 1998; Sharma et al. 2016; Chapagain, Ghimire & Shrestha 2019). Systematic studies of the mountain springs in western Nepal have shown that occurrence, distribution, and change dynamics are poorly understood (Negi & Joshi 2002; Chinnasamy & Prathapar 2016). Spring sources research initiated in the region has documented widespread concern about drying springs sources (Adhikari et al. 2021) and highlighted the increasing water crisis (Gurung et al. 2019) in western Nepal. Thus, scientific evidence-based policy responses are crucial for sustainable spring watershed management (Mahamuni & Kulkarni 2012). However, questions on spring dynamics relating to microclimatic variation, land use change perspectives, and social hydrology, remained unanswered (Adhikari et al. 2021).

To investigate and help answer these questions, this research examined the status of springs in a typical mid-hill watershed in Far West Nepal through physical mapping of spring sources, validating the spring flow trend with community perception, and gaining an understanding of the supplementary aspects of spring dynamic. Among several causes and consequences of changing dynamics of the mountain springs, this study investigated LULC change trajectory analysis and climate change indices quantification followed by cross-validation with spring flow trend and community perception. Thus, this study helps to fill the gap in knowledge associated with the recent reports of depleting water from the traditional spring sources of the mid-hills of Himalaya. Furthermore, this study provides policy recommendations for a sustainable water resource management approach in Rangun Khola watershed of Far West Nepal.

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Figure 2: Map of Nepal (UN 2007)

1.2 Objectives

The broad objective of this research is to gain an understanding of the spring water dynamics of the Rangun Khola watershed in the mid-hills with respect to changing climate and land use patterns. The study has three specific objectives, which are:

i. To assess spring water availability and trends in Rangun watershed
ii. To evaluate impacts of LULC and climate change on spring resources in the Rangun Khola watershed
iii. To evaluate the implication of changing spring water dynamic on communities

1.3 Thesis structure

The thesis has six chapters. Chapter I provides the background to the problem of declining natural spring flows in the Himalayas and identifies the current gap in research and knowledge on the issue. This chapter further illustrated the significance of the study in the chosen study area and ultimately outlined the research objectives. Chapter II is comprised of a detailed review of the body of literature on different aspects of spring research. The chapter begins by defining and classifying springs in the mountain setting and explaining the importance of springs to the environment and communities. The reviewed literature is arranged in the order of changing spring dynamic, opportunities and challenges, and existing research gap. Chapter III elaborates the study area description and applied methodology. In the study area description, the general setting of the Rangun Khola watershed is presented with a highlight to its geology, while the methodology section summarized the applied tools, techniques, and approaches for data collection and analysis in the research. Chapter IV discusses the results and outcomes of the study, which are arranged in sequential order of physical, climatic changes evaluation and cross-validation with spring source mapping, community perception, and other secondary data set information. Chapter V discusses the findings in relation to the available supportive literature. The final Chapter VI forms the conclusion which summarizes the overall research output and includes a recommendation section highlighting the need for proper water resource management planning and further research in the Rangun Khola watershed.

II. LITERATURE REVIEW

2.1 Spring introduction and classification

The occurrence of water on the earth's surface is not by chance; rather, it is governed by various factors, including geology, hydrogeology, physiology, ecology, and climate (Andermann et al. 2012). Springs represent the location of the earth's surface where the combination of hydrogeological components is resulting in the visible flow of groundwater discharge. Unlike wells, springs are the natural discharge points of aquifer providing water in the natural flow system. Springs are one of the imperative portions of the hydrological cycle in the mountain. Underground geology, including characteristics of rock types, presence or absence of fold and faults, plays a vital role in spring emergence (Soulios 2017). The diffused water is termed seepage, whereas the water localized at areas of fault or fissures is termed a spring (Price 2002). The existence of a spring is the consequent outcome of a variety of conditions with varying circumstances; therefore, springs are classified differently according to differing characteristics, for example, based on their genesis, rock structure, discharge rate, or temperature (Hackett 1998).

Even though there is a lack of consistency in classification of springs, (Springer & Stevens 2009), springs can be differentiated based on common parameters and characteristics. For example, a spring originating from the high-pressure zone of the confined aquifer due to the exposure of piezometric head with the land surface is termed an artesian spring or rising spring (Kresic 2010). A spring emerging from an unconfined aquifer with a water table intersecting the land surface is termed a gravity spring or descending spring (Bryan 1919). Other springs are classified as depression springs, contact springs, fracture springs, karst springs, and fault springs, based on the underground geology and surface interaction (Fetter 2014). However, Meinzer (1923) classified springs into eight different classes based on flow rate (Table 1).

Table 1: Discharge rate-based spring classification (Meinzer, 1923)

Discharge Magnitude	Discharge
First	>10 m^3/s
Second	1 -10 m^3/s
Third	0.1-1 m^3/s
Fourth	10-100 l/s
Fifth	1-10 l/s
Sixth	0.1-1 l/s
Seventh	0.01-0.1l/s
Eighth	<0.01 l/s

2.2 Characteristic of mountain spring resources

From a human perspective, springs in the Himalayas carry profound religious, spiritual belief, and cultural affiliations which are important to many village communities (Andermann et al. 2012). Hence, springs are often preserved as sacred places and, in this sense, springs form an inseparable component of the ethno-cultural, traditional ecosystem supporting communities (Risko 2018).

Negi and Joshi, (2004) studied the rainfall and spring flow pattern of six springs in two micro watersheds in western Indian Himalaya. The authors found that mountain springs predominantly fed by precipitation and flowing from unconfined aquifers were mostly controlled by climatic pattern, recharge area, and aquifer characteristics which showed significant positive correlation of spring discharge with rainfall. The studied spring sources were classified into two categories, fractures/joint/colluvium and fracture/joint springs based on internal geology. The rainfall spring discharge interaction for these two categories of spring showing significantly different behaviour verified the differential groundwater interaction with differing geology. Normally, mean annual discharge for fracture/joint/colluvium springs was twofold greater than fracture/joint springs. However, spring discharge per rainfall was more than two times higher in the case of fracture/joint springs. The discharge comparison revealed that fracture/joint springs which had weak relation to rainfall were considered suitable for long-term sustainability.

Vashisht and Sharma (2007), analysed eight years of spring hydrological behaviour of perennial springs with rainfall variation in Uttarakhand, western Himalaya. It was reported that the time required for the water to travel from the remotest location of the spring catchment was 57 days. It was thus revealed that spring discharge was highly dependent on local water availability in the form of rainfall and its resultant interaction with the ground. Therefore, springs and small seepage canals management in the Siwalik foothill regions of the Himalayas could be one of the risk averting interventions in the event of increasing water scarcity in the mid-hills (Vashisht & Sharma 2007) .

Jeelani's (2008) study of forty perennial springs in Kashmir Himalaya using the velocity area method, sought to identify the spring discharge response to the regional climate variability. The 23-year spring monitoring study, classifying the springs based on the underlying geology, reinforced the observation that spring discharges in the karst and alluvial springs in the Himalayas were decreasing. Furthermore, the study also revealed that Himalayan spring discharge is strongly correlated with the snowmelt rather than precipitation. This finding explains why global warming and reduced precipitation during the snow accumulation period accounts for triggered snowmelt and consequent attenuation in the spring discharge in Himalaya springs (Jeelani 2008).

In Fiorillo's (2009) research on large karst systems in southern Italy, spring discharge was analysed to determine the relationship between precipitation and ground recharge. The study revealed that the microclimate of a locality and aquifer geology have a direct relation to the karst spring hydrograph. Among the climate parameters, resultant available rainfall shows a strong correlation with average spring discharge. The cumulative storage of water volume in the karst aquifer is strongly linked to the long-term climate trend. The study revealed that annual rainfall series do not have a random character; however, aquifers have a "memory effect" in that the hydrological year depends on the previous year's performance of hydrological parameters. The consecutive years of below-average rainfall are therefore expected to show a continued decrease in discharge, which may lead to a spring drying up over time. This phenomenon is credited to spring discharges amplification due to poor effective rainfall and altered temperature trend. The study thus suggests that altered global climate trends (i.e., negative rainfall trend and positive temperature) are expected to result in more frequent flat spring hydrographs as compared to the past (Fiorillo 2009).

Chauhan et.al (2011) assessed the natural springs, the main source of potable water in the Garhwal area, in the western Himalayas. The physicochemical and biological parameters (e.g., alkalinity, acidity, DO, BOD, free CO2, nitrate, chlorides, hardness, pH, and coliform number) of the water were recorded on a monthly basis. It was reported that in the Garhwal Himalayas, upper dense broad-leaved Quercus and Rhododendron forest absorbs rainwater during monsoons, and slowly releases water from the catchment over the year supporting numerous natural springs in the watershed.

The water quality assessment revealed that the quality of most of the water samples under study was suitable for drinking purposes (Chauhan, Chamoli & Pande 2011).

Mahamuni and Kulkarni (2012) documented the spring characteristics, including the location, physical and chemical properties, of 15 Himalayan springs in the Sikkim region. Their study revealed that spring discharge associated with infiltration pattern is dependent on the hydrogeological properties of the underlying aquifer as well as the microclimatic variation in the catchment.

Tambe et al. (2012) conducted action spring research in the eastern Sikkim Himalaya to understand the spring characteristics and revival possibilities. The study revealed that a dotted network of micro springs, supporting an average of 30 households per spring, is a crucial component for rural subsistence livelihood in the mountain communities. The annual periodic rhythm study of spring discharge revealed the overall decline over the previous decade in spring discharge, amounting to 35% in the general area and 50% in drought-prone area, with slight variation in terms of magnitude. The authors suggested a combination of physical and hydrogeological improvement approach adapted for spring revival as one of the techniques for spring source conservation in the changing scenario. In addition, rainwater harvesting in the spring shed area was suggested as a relevant technique contributing to increasing lean period discharge and even enhanced flow in the dry period. These measures would serve to strengthen the community resilience against climate change. The paper highlighted the importance of the spring shed management approach, such as identifying recharge area, local capacity development, incentivizing rainwater harvesting at the community level, and supportive financing opportunities, and reiterated the need for more action researches in the mountain (Tambe et al., 2012).

Agrawal et al. (2012) monitored 50 springs, nine automatic rain gauge, and two rivers gauging in two mountain watersheds in Uttarakhand, over 11 years. Daily measurement of spring flow for more than a decade revealed that the spring discharge showed a strong correlation between the precipitation and concurrent recharge. A range of water conservation techniques, such as drip irrigation, installation of water conservation structures, and capturing the rainwater, was recommended as a measure for increasing water retention power of each watershed (Agarwal et al. 2012)

The 11-year study done by Agarwal et al. (2012) in western Indian Himalaya investigated the spring specific water stress scenario of two watersheds in the Uttarakhand. The power regression relationship between annual spring flow and rainfall on yearly basis indicated the existence of high correlation between the two components. The spring discharge in two watersheds was thus directly related to precipitation. Daily observation of spring flow data applied for time lag calculation revealed a daily measured lag of between 1-30 days while the monthly lag extended up to 2 months. The water budget estimation for the study area revealed that water availability was a limiting factor for water use in the mountain. In the scenario of increasing water demand with consequent degradation in spring flow as a resultant effect of physical and climatic stressors springs, the author identified the dire need for increasing water retention capacity of spring shed along with maximizing efficient utilization of the available spring source (Agarwal et al. 2012Agarwal; Agrawal & Nema 2014).

Andermann et al. (2012) analysed rainfall and discharge data over three decades, and identified annual hysteresis loops in the mountain catchments in Nepal. The study showed that groundwater storage in the fractured geological formation shares a significant portion of spring discharge in the Himalayas. The occurrence of groundwater is greatly influenced by the interaction of the climatic, geological, hydrological, physiographical, and ecological characteristics (Andermann et al. 2012).

Bhushal and Gyawali (2015) analysed the suitability of 30 spring sources of the Badigad Catchment from Gulmi and Baglung for irrigation and drinking purposes in Terai and Hilly regions respectively. The water quality assessment revealed that springs in the Badigad catchment were in the permissible National Standard for Drinking and Irrigation and World Health Organization standards for drinking water quality. It further indicated that springs originating from non-carbonated rocks have a slightly lower value of chemical parameters as compared to those from carbonated bedrocks (Bhushal & Gyawali 2015).

Mocior et al. (2015) conducted extensive mapping of 879 springs across Polonina Wetlinska in Poland, followed by statistical assessment of spring distribution in the study area. The research identified that the distribution of springs in the study areas was affected by the combination of interdependent geological and morphological factors. The underlying geology in form of rock type and slope of the area is the determining factor for spring distribution. Some springs arise due to tectonic faults and fractures. In addition, the very presence of any slope positively affects the probability of the occurrence of a spring in a given area (Mocior et al. 2015).

KC and Rijal (2017) studied the geomorphology of springs in the Khar area located in the Darchula district, Far-western Part of Nepal. Emphasizing the importance of springs in the livelihood of the mountain community, the study presented the unique geomorphology of mountain springs. Discharge and physicochemical properties assessment was conducted for 57 mountain springs, revealing the depression springs concentration in the northern slope and fracture springs in the southern slope in the Khar area. The discharge monitoring which was done for a year revealed the direct relationship between mountain springs and the microclimatic variation, especially in terms of precipitation patterns (KC & Rijal 2017).

Another recent study by Ghimire, Chapagain and Shrestha (2019) identified the groundwater spring potential zones of the Himalayan mountain slope in the Melamchi area in Central Nepal. The groundwater spring potential was accessed using 11 factors, which indicated that areas of gentle slope, low relative relief, high flow accumulation, north- and east-facing slopes, denser lineament density, altitude class of 1500–2500 m, high vegetation density, and forest had a higher likelihood of spring occurrence. The groundwater spring potential map was validated with field data which indicated that the spring potential map provided the validated measure in case of unavailability of the hydrogeological or geophysical dataset (Ghimire, Chapagain & Shrestha 2019).

Tiwari et al. (2020) studied 57 spring sources based on distribution, occurrence quality, and quantity land-use patterns, their occurrence and uses, in the Helambu area in Central Nepal. The spring characteristics (e.g., water quality, water availability, discharge, geochemical properties, sources, and usage, and potential health hazards) assessment in Helambu revealed that springs are crucial for the communities in the mountain. As reported by the communities, 19 out of 57 springs dried up and 5 springs originated after an earthquake event. The change in geology created by the earthquake led to implications on water flow dynamics in the study area which verified that formation and water flow in springs was mainly controlled by topography and underlying geology. Water quality assessment reported that the studied spring sources had an excellent condition from the quality perspective. However, long-term water quality monitoring was recommended for sustainable water resource management since Helambu is a tourist destination and overuse of the resource could result in degradation (Tiwari et al. 2020).

The spring flow assessment done by Dass et al. (2021) in the micro watershed in Indian Himalaya applied hydro-geological studies to assess the possibility for spring revival in the watershed. The water balance, regression, and geological assessment investigation carried out in two different watersheds revealed that the hydrogeological characteristics of two micro watersheds determine the flow velocity of the springs. In the given example of Shiv gadera, which has an intricate flow network and slow velocity, springs were found to be perennial with more groundwater contributing to the flow. In contrast, springs in Haraita, which is characterized by transmissive fractured rock, have more intermittent to ephemeral nature. Similarly, uniform geology and diversity of recharge area promote stable long-term recharge with slow emptying rate, as in the case of Shiv gadera micro watershed, which is in contrast to the case of the Haraita shallow storage aquifer that exhibits a quick response to storm events leading to a quicker impact on the aquifer storage. Spring shed characters are thus one of the factors for determining the spring discharge response to changing environment. Therefore, understanding the hydrogeological characteristics of spring shed is one of the vital components for sustainable spring shed management intervention in the mountain (Dass et al. 2021).

2.3 Drying spring sources in the Himalayas

The body of research literature on springs throughout the Himalayas shows an increasing trend over the past 50 years of changing spring flow regime and drying up of the existing sources(Poudel & Duex 2017) . Presenting the evidence from more than 40% of the villages in western Himalaya reporting diminishing spring flow, the study done by Valdiya and Bartarya (1991) confirmed the vulnerable spring situation. Furthermore, their study demonstrated consequent spring flow change in chronological order, which showed a 29.2% decline in stream flow and discharge between 1951-1960 and 1961-1970, and further decline to the level of 38.5% between 1971 and 1981. The authors attributed spring discharge deterioration to the altering rainfall pattern in the catchments (Valdiya & Bartarya 1991).

In the central Himalayan region, Negi and Joshi (2002) reported more than 35% of springs were already dysfunctional, leaving only 64% as functional among the 5,804 government drinking water schemes. Among the dysfunctional springs, almost 15% were completely dried out while 21% were only partially operating (Negi & Joshi 2002).

Merz et al. (2003) discussed the water availability scenario in Jhiku and Yarsa watershed in the middle Himalayan region, Nepal. Documenting local people’s perception of water-related issues, the paper presented qualitative and quantitative assessments of water accessibility in the study area. Comparative assessment of water demand and supply in two mountain watersheds revealed that water availability was following a declining trend while demand was rising with agricultural intensification and change in human lifestyle. This contrasting difference between water demand and supply has been exerting pressure on available resources for many years. Henceforth, novel and innovative water resource management interventions incorporating the local knowledge with scientific methods and techniques were recommended by the authors to tackle the increasing pressure on the available water resources (Merz et al. 2003).

The study done by Mahamuni and Kulkarni (2012) identified drying spring sources as one of the prominent reasons for acute water shortage in the Himalayas. The authors recommended that understanding the spring dynamic from multiple aspects and incorporation of local voice is crucial for sustainable resources management in mountain watersheds (Mahamuni & Kulkarni 2012).

More recently, Chapagain, Ghimire and Shrestha (2019) examined 412 groundwater springs to understand the status of groundwater springs in the context of changing climate in the Himalayan slopes of Central Nepal. In the phases of investigation, the documented spring sources were characterized in terms of distribution, discharge, utility, and status in the context of changing climatic scenarios. Almost 30% of the documented springs showed a decreasing trend in the recent past, which indicated that declining natural spring sources are concurrent with the rapidly changing local climatic scenario(Chapagain , Ghimire & Shrestha 2019).

Adhikari et al. (2021) conducted extensive spring source mapping of 4,222 spring sources in five watersheds in western Nepal. The study reported the prominent dependency of rural mountain people on natural springs and reiterated the importance of spring resources in water demand fulfilment. Of the authors found that 70% of spring sources were showing declining discharge which highlighted the seriousness of the problem. Supported by the documented status of declining water availability, the study showed the need for urgent action research for spring source conservation in western Nepal (Adhikari et al. 2021).

2.4 Stressors for spring resources management in mountain

There is increasing evidence that, as with many principal ecosystems in the world, natural dynamics and anthropogenic stressors are imposing pressure on groundwater systems (Somers & McKenzie 2020). Many drivers are exerting influences on the sustainable management of the freshwater supply system in the Himalayas (Poudel & Duex 2017). The harsh mountain topography and climate further add to the problems of water scarcity and diminishing resource availability for the mountain communities (Portnov, Adhikari & Schwartz 2007). There is ample evidence showing that mountain regions are subjected to greater changes and fluctuations in temperature and rainfall patterns as compared to lowland areas (Wester et al. 2019). As with other global environments, pressure from human population growth and activity in the Himalayas is impacting sustainability of resources. These factors combine to pose a serious threat to the mountain environment with greater implication on the overall hydrological regime and flow of springs associated with the mountain ecosystem (Barnett, Adam & Lettenmaier 2005).

Valdiya and Bartarya (1989) assessed the trend of change in discharge in the mountain springs in a part of Kumaun Himalayas and provided an appraisal of the fast-changing pattern of land use and its impact on water resources. The study reported that, deforestation of vulnerable hill slopes over 35 years (1951 to 1986) had led to a 13.1% reduction of the protective forest cover. Furthermore, deforestation triggered accelerated erosion at the rate of 170.3 cm/1000 years, which has greatly affected the hydrologic regime of the catchment. This alteration in hydrology is manifest in the drying up of springs and the diminished discharges in more than 40% of villages of the Gaula Catchment in Kumaun Himalayas (Valdiya & Bartarya 1989).

The investigation of the underlying causes of drying spring sources in mountains (Negi & Joshi 2002) revealed that the common pressure from LULC changes and deforestation is further imposed by the increasing burden of development and human population growth. These increasing stressors caused by free access to mountain springs sources are additionally adding to the problem of the "tragedy of commons". Spring resources that are shared and uncontrolled may be overexploited and mismanaged due to non-excludability of users and lack of coordinated approaches to sustainability. The article described the field interventions carried out for spring revival between 1995-2000 and the resultant successful effect on spring restoration in the study area, which highlighted the importance of action research followed up with supportive local interventions for spring source protection in the mountain environment (Negi & Joshi 2002).

Joshi (2006), who studied hydrological behaviour and nutrient dynamics of eight springs in the Indian central Himalaya basin, found that spring sources were drying up and verified the disappearance of perennial springs in the study area. The research indicated that high deforestation, denudation, and intensive pressure from demographic changes were exerting pressure on the quality and quantity of spring resources. The comparative assessment of the spring sources in different landforms revealed that reserve forest has comparatively higher water retention capacity as compared to other landform uses. Thus, the LULC of the ground surface has greater implications in water quality and groundwater recharge (Joshi 2006).

Poudel and Duex (2017) researched vanishing springs in mid-hill in central Nepal. The study documented the status of 41 springs within the watershed along with a questionnaire survey of 97 households (HH) and supplementary focus group discussions (FGD) and participatory rural appraisal (PRA) to document community perceptions about changing water resource dynamic and community adaptation mechanisms. The research indicated population growth, agricultural intensification, land-use changes, and deforestation as possible factors impacting the water resources at the local level. Furthermore, it identified economic development and climate change as supplementary burdens on declining water resources which were aggravating the water shortage. Limited adaptation options, such as constructing water tanks at water sources, using pipes to transport drinking water, diverting water from other springs, digging deeper wells, and traveling farther to wash clothes and fetch drinking water, were initiated by the community. The authors urged more comprehensive research on spring dynamic in association with the surrounding environment, followed by corrective actions on the ground (Poudel & Duex 2017).

Another study by Chapagain, Ghimire and Shrestha (2019) found that rainfall variability, decreasing useful rainfall, and increasing anthropogenic activities, including degradation of the catchments, land-use change, and development of infrastructures such as road networks, have disrupted the hill slope hydrology in the middle mountains of Nepal. The authors also documented the case of the 2015 earthquake when almost 18% of springs dried up immediately afterward. This event demonstrated how tectonic activities such as large-scale earthquakes exert additional pressure on pre-existing challenges for natural spring sources. The decreasing water availability was found to be impacting local livelihoods, however, no significant actions were noted at the community scale. These continual pressures on spring sources in the mid-elevation range, without any adaptation intervention, is predicted to increase the risk for natural springs, especially in the discharge limit of 5 l/m (Chapagain, Ghimire & Shrestha 2019).

Sharma et al. (2019) examined the geo-lithology and the hydrogeology of the springs and identified critical springs with high human dependency in the Chibo–Pashyor watershed of Kalimpong district, West Bengal. The mapping of 55 spring sources in the area of this study helped to explain the causes behind the drying up of springs. Based on the study of critical springs in the watershed, the paper presents a set of recommendations related to key issues of governance and management. The major hindrances in water governance in Chibo–Pashyor area were highlighted, including limited local level participation, poor community awareness, and lack of timely monitoring and maintenance of water infrastructures. These findings emphasized the need for integration of spring shed management within a climate change adaptation plan for sustainable water resource management in the area (Sharma et al. 2019).

Saraswati et al. (2020) investigated the hydrological response of forest road extension on local groundwater flow and its implication on mountain watersheds in Attica Greece. The study applied a combination of methodology ranging from field data analysis supported by the spatial and hydro-meteorological database to simulate the hydrological response phenomenon. The study found that road cut slopes obstruct the natural water flow regime to abridged groundwater infiltration rate with subsequent incremental increase in surface runoff leading to long-term implications on geomorphology and ultimate groundwater hydrology of the watershed. The paper reiterates the importance of understanding watershed hydrological responses for sustainable development intervention in a watershed (Saraswati et al. 2020).

2.5 Research gaps in spring studies

Mountain spring sources are the greatest contributors to water demand fulfilment for rural mountain communities. However, studies of mountain springs are often discounted as compared to studies of basin-level water resources (Rasul 2014). As described in this literature review chapter, there have been quite a number of studies in the greater Himalaya region over the past 50 years that have revealed the nature and extent of declining spring flows and the aggravating causes of springs drying up (Tambe et al. 2012; Tiwari et al. 2020). Despite this relatively large body of research, there remains a gap in knowledge on how the impacts of climate change on recharge mechanisms may vary according to aquifers and regions of the Himalayas (Wester et al. 2019). Therefore, a gap exists on timely documentation of status and trends of spring sources within the Himalayas.

Merz et al. (2003), in their paper based on the water scarcity problem identified by Merz, Nakarmi and Weingartner (2003), suggested that traditional or scientific knowledge cannot succeed in isolation. The authors explained that day-by-day increasing challenges in the sector of water management can only be solved by proportional integration of traditional and scientific approaches for novel water management solutions. The paper proposed a number of approaches, including supply management (water harvesting, groundwater, fog collection), alternative water application (drip irrigation), demand management (water conservation), and quality management (low-cost water treatment, catchment, and spring protection), for improving sustainability of water resources (Merz, Nakarmi & Weingartner 2003). Therefore, a gap exists in the need to develop a greater understanding of how traditional, indigenous methods of water management can be integrated with scientific approaches to create novel solutions in the community setting.

The study by Mahamuni and Kulkarni (2012) identified drying spring sources as one of the prominent reasons for acute water shortage in the Himalayas that need timely action on the ground. Thereafter it was recommended that understanding the spring dynamic from multiple aspects and incorporation of local voice is crucial for sustainable resources management in mountain watersheds (Mahamuni & Kulkarni 2012). Research on achieving greater involvement and incorporation of local stakeholders in water management therefore represents a gap in the literature.

The research on spring revival between 1995-2000 carried out by Negi and Joshi (2002) investigated the resultant effect on spring restoration in the Indian Himalayas. The study highlighted the importance of action research followed up with supportive local interventions for spring source protection in the mountain environment (Negi & Joshi 2002).

Sharma et al. (2016) investigated the spring issues, and tested some possible solutions in a typical mid-hills area of Nepal with the help of an action research project. The research explored the function of springs at the local level in a social context, knowledge of the hydrogeological formations, and water recharge. Reiterating the importance of springs in the livelihood of the mountain community, the paper highlighted the issue of declining numbers and discharge in the springs in the mid-hills. They argued that people have started searching for alternative options for supplementing water demands, including piped water from distant sources, tapping available groundwater, or harvesting rainwater. However, the efforts of local people and institutions to understand and address the root causes of disappearing springs remained limited. Directing attention to the completely overlooked problem of over-extraction and failure to recharge groundwater restoration, the paper concluded with recommendations on the need for in-depth research and actions for spring source restoration (Sharma et al. 2016). A clear gap in local and institutional awareness of the problem of over-extraction and lack of recharge in this instance could be reduced through more prominent and far-reaching public education.

Regmi and Shrestha (2018) highlighted the policy gaps and institutional arrangement shortcomings for water resource management in Nepal. Traditionally, locals have been in charge of national resource management (NRM) followed by timely evolving norms, practices, and institutions. The central government is mainly responsible for policy and law formulation. In the case of Nepal, abundant laws and policies have been formulated; however, the gap remains in the implementation phase. The foremost hurdle is the lack of science and fact-based data and knowledge for evidence-based policy formulation and missing linkage between upstream and downstream communities and improper power distribution. In the context of climate change and increasing CC-related risk, policy modification is necessary. Dimensions of mainstream CC in the development policies have been researched, however, the influence of policy framework and institutional structure on water resource management in the context of changing climate is still lagging (Regmi & Shrestha 2018).

III. MATERIALS AND METHODS

3.1 Study area

In the far western part of Nepal, two Siwalik hill ranges around Rangun Khola, make up the Rangun Khola Watershed (Dhital 2015). Rangun Khola watershed, one of the seven watersheds in the Mahakali River Basin, is located in Sudur Paschim Province. The watershed falls mostly in the Dadeldhura district (Parashuram municipality and Alital rural municipality) and touches slightly a portion of the Jorayal rural municipality in Doti district (Figure 3). The watershed extends from the southern confluence of the Mahakali River to the northern proximity of the Mahabharat range. The Uttarakhand in India is the western border of the watershed, while Kanchanpur district forms the southern border of the watershed (Paani 2019).

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Figure 3: Map of Rangun Khola watershed (Paani, 2019)

3.1.1 Topography, demography and climate

The watershed occupies an area of 687 km2 within the elevation range of 300 m to 2,500 m. The steeply sloping topography of the watershed together with high rainfall makes it susceptible to flood, landslide, and river cutting. The watershed population of 53,514 people represent a rich ethno-linguistically diverse community with 8.8% Indigenous (Janajaati), 75.8% Brahmin Chhetri Thakuri Sanyasi, and 15.2% minority (Dalit) groups (CBS 2011).

The climate of the study area ranges from a tropical climate in the south to a warm temperate climate in the north and, with local variation in temperature with gradient, the average annual temperature ranges from 10°C to 25 °C in the watershed. The precipitation varies according to season, the average annual rainfall is 1,346.6 mm for the watershed with the highest amount of rainfall (448.4 mm) received in July during the monsoon season, while the lowest (7.3mm) is recorded in the winter month of November.

3.1.2 Hydrogeology

Rangun Khola is the major river system in the watershed, which is fed by 135 tributaries along its course, and joins Puntura Khola before meeting Mahakali River in the downstream area. Wetlands, such as Ali Tal, Pipalkot Tal, and Kumad Gad, are additional water resources available in the watershed. Extensive river gravel deposition is a distinctive feature in the Rangun Khola watershed.

The mountain ridges comprised of Precambrian augend, banded gneiss, and various mixtures of mica-schist and phyllites, characterize the geology of the Rangun Khola watershed (Figure 4). Mahabharat Range is the higher peak of the watershed. An active fault (Figure 5) passes in the proximity to the main boundary thrust and runs through Budar, Alital, and Kalena (Dhital 2015).

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Figure 4: Geology of Rangun Khola watershed (ICIMOD, 2020) `

Table 2: Lithology of Rangun Khola watershed (ICIMOD, 2020)

Code	CLASS	Lithology
21	Granites	Palaeozoic granite
19	Sallyani Gad Formation	Neoproterozoic to Cambrian Aplites ,granitic ,gneiss, augen gnesis and biotite gneiss
22	Basic Rocks	Phyllites, amphibolite, Metasandstone, graphite schist
33	Gn	Gnesis
202	Bu	Major Carbonate Band
14	Ranimatta Formation	Upper Pre-Cambrian to Late Palaeozoic Gray to greenish-gray, gritty chloritic phyllites and phyllitic quartzite, metastone and conglomerate beds with white massive quartzite.
11	Syangja Formation	Upper pre Cambrian to late Palaeozoic origin white to milky white pale orange purplish calcareous quartzite and dolomitic limestone with dark-gray shale.
12	Sangram Formation	Upper pre Cambrian to late Palaeozoic origin Black laminated shales with thin limestone and quartz granite interbeds
33	Gn	Gnesis
14	Ranimatta Formation	Upper Pre-Cambrian to Late Palaeozoic origin Gray to greenish-gray, gritty chloritic phyllites and phyllitic quartzite, metastone and conglomerate beds with white massive quartzite.
5	Lower Siwalik	Siwalik is Neogene sedimentary cover on the ridge Siwaliks resting on the Pleistocene alluvial terraces.
4	Middle Siwalik1	Siwalik belt, characterized by its relatively simple lithology and spectacular sedimentary structures, is presented in. This zone has also undergone significant compression and shortening, as revealed by many folds and imbricate thrusts
2	Upper Siwalik	Upper Siwaliks -composed of conglomerates, consisting of much the same material as that which forms the present streambed
3	Middle Siwalik2	Composed of light grey sandstone

A conspicuous active fault that developed in the Rangun Khola watershed of the Mahakali–Seti region, is included as the fault within this Main Boundary Active Fault System (Figure 5 a & b). Although the active fault runs very close to the Budar Thrust, it diverts significantly from that fault around Alital while crossing the phyllites and quartzite of the Lesser Himalaya. The Budar Thrust lies a few kilometres farther south of the active fault. Except for beautiful Lake Alital, most of the sag ponds developed along this active fault are already silted up. The sag ponds and the "pressure ridge" lying to the south, on the footwall of the fault, imply a normal sense of movement along the active fault (Dhital 2015).

Image removed due to copyright restriction.

Figure 5 (a & b): The Rangun Khola active fault occurring in the Mahakali–Seti region (Dhital, 2015)

3.2. Methods

The overall methodological framework is shown in Figure 6. Both primary and secondary data were analysed to assess the status of springs, trends in spring discharge, analysis of peoples' perception, and changes in climate as well as LULC change. Methods for each component are elaborated in the following sub-chapters.

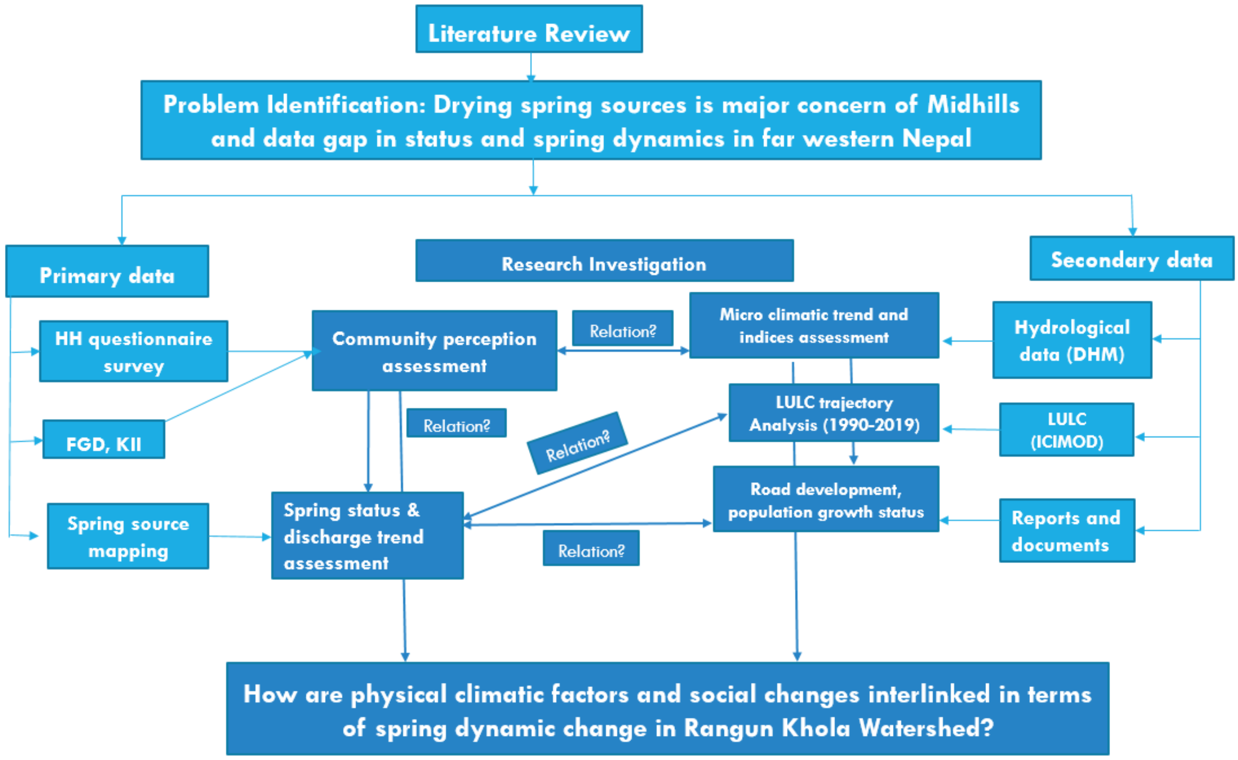


Figure 6: A research framework

3.2.1 Spring source mapping and trend analysis

The spring source location was mapped manually with Global Positioning System (GPS) by a team of experts and trained citizen scientists. The details of each spring including location, aspects, type, surrounding environment, use, dependency, flow rate, and trend were collected using a mobile application, with a structured questionnaire uploaded in Kobo Toolbox (https://www.kobotoolbox.org/). The spring discharge was estimated by bucket, surface floatation method, and verification was done by recall method during November 2018. Time taken to fill a 20-liter vessel at present and 10, 20 years ago was applied for the flow rate validation purpose (Adhikari et al. 2021). The data obtained from the recall method were derived as spring discharge and trend analysis was performed to see the variation in spring flow in the watershed. Even though the past flow was recorded through the recall method the present flow measurement done by bucket and float method, which helped to cross-validate the perception data obtained by the recall method. All the location coordinates of the springs, recorded using GPS, were converted to ArcGIS shape files point features for further analysis. Among the 1,122 springs mapped in the Rangun Khola watershed, the bucket method was applied to measure the flow of 761 springs, followed by the perception method of 328 springs and float method of 33 spring sources (Figure 7).

The data of 1,122, spring sources mapped was then applied for further assessment purposes. Among the spring sources, continuous flow data were available for 848 springs, which was applied to conduct the discharge trend assessment. In addition to documenting the status of a spring, discharge trend, and community dependency, this study investigated the pattern of spring flow concerning changing land-use dynamics. The spring flow rate was documented according to the time taken to fill a 20-liter jar and calculated as liter per second for the present flow rate calculation. For the past flow rate, data collected through the recall method was quantified in terms of a liter per second. The same flow rate was quantified for each spring according to 20 years ago, 10 years ago, 5 years ago, and now, and was then applied to categorize the spring as increasing, decreasing, or no change classifications. Similarly, the same flow rate was applied to determine quantified comparison of flow decrease trend in terms of decreased by less than 25%, less than 50%, or more than 50%. This discharge rate was then applied to access the changing spring flow dynamic in the Rangun Khola watershed.

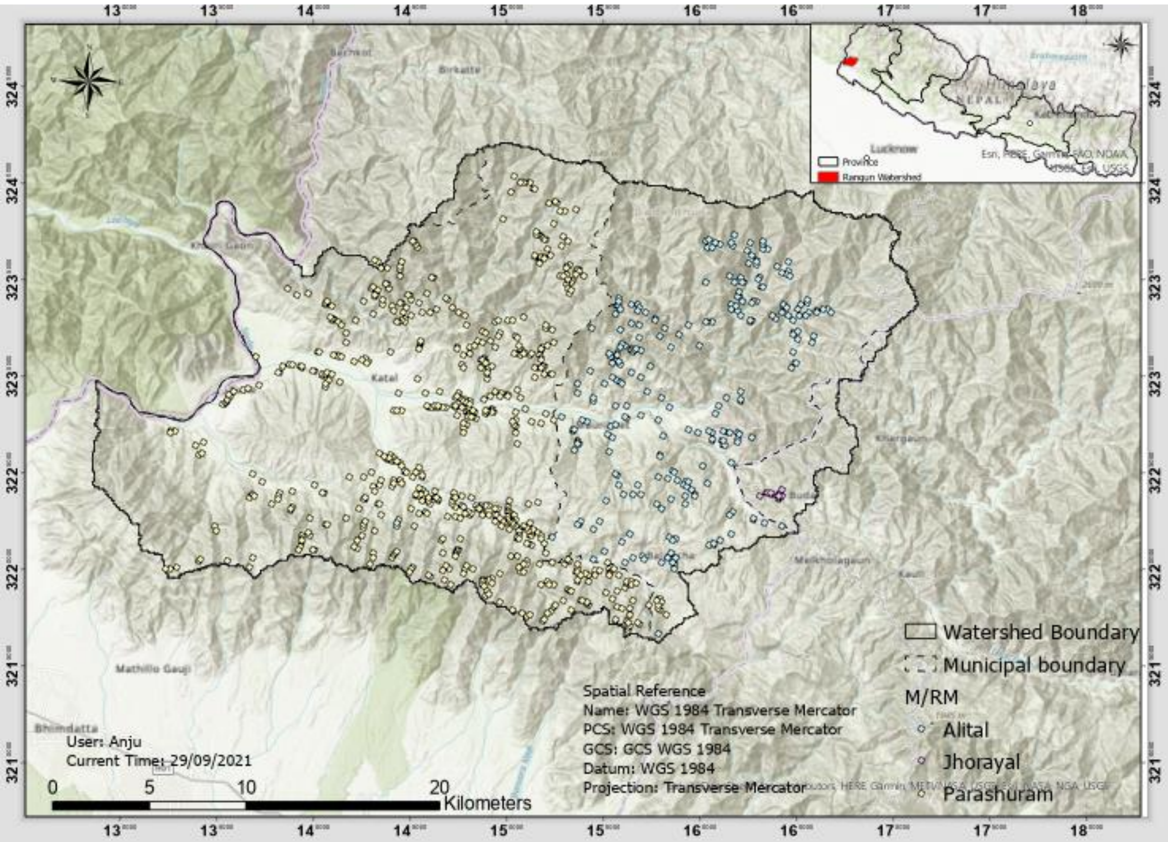


Figure 7: Spring sources mapped in Rangun Khola watershed

The springs classification was conducted based on flow rate as demonstrated by Meinzer (1923), where springs were classified into eight different classes.

3.2.2 Household perception assessment

A household questionnaire survey (Appendix A) of 232 households, spread through three municipalities within Rangun Khola watershed (Figure 8), which was conducted by the USAID Paani program in 2018, was used to understand water source management impact and implication issues related to the perception of communities in the Rangun Khola watershed (Paani 2019). The HH survey documented information on household dependency and accessibility to water sources, the perceived implication of changing water availability, and climate change variability. Simple statistics such as mean, standard deviation, frequency, and range were calculated using MS-Excel for community perception assessment.

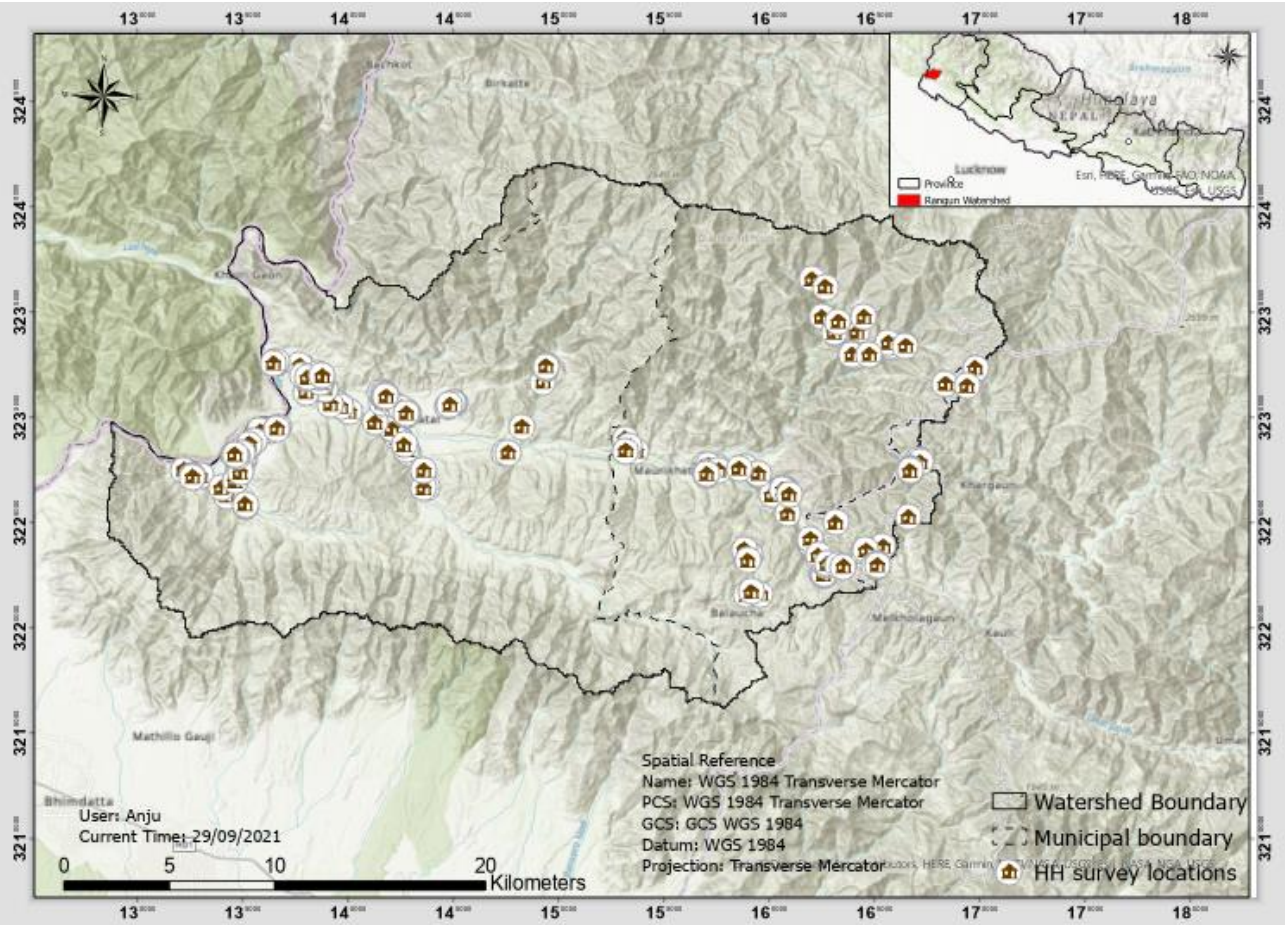


Figure 8: HH questionnaire survey map

3.2.3 Hydrometerological trend analysis

Daily precipitation and temperature data of Dadeldhura meteorological station, from 1980 to 2017, collected from the Department of Hydrology and Meteorology (DHM) was used for climatic trend analysis. Due to the absence of a meteorological station within the watershed, the closest Dadeldhura meteorological station was referred for long-term precipitation and temperature data collection. Rainfall and temperature data received from DHM were directly used while there was some limitation in evapotranspiration data. Calculation of reference evapotranspiration requires accurate measurement of air temperature, relative humidity along with solar radiation, and wind speed. The Dadeldhura meteorological station was lacking good quality continuous and accurate data on solar radiation so classical methods, such as the Penman-Monteith method, could not be applied. Henceforth, the Hargreaves method (Hargreaves & Samani 1982), for potential evapotranspiration calculation, was used for potential evapotranspiration (ETo) calculation from temperature data using the following equation (Equation I):

$ETo = K_{ET} * R_A * (T+17.8) * TD^{0.5}$ ………………….Equation I

Where KET is the Hargreaves method's empirical coefficient=0.0023, RA is extra-terrestrial radiation, TD is the difference between the maximum and minimum temperature and T is the average temperature (Jung, Lee & Moon 2016).

Monthly precipitation, temperature, evapotranspiration, and net rainfall data were used to generate annual and seasonal time-series analyses of spatiotemporal change in climatic patterns (Nema et al. 2018). The statistical significance of the trend was investigated using non-parametric Mann-Kendall tests (Mann 1945) in the R program, which is a widely applied trend analysis method for climate data (Khatiwada et al. 2016; Silwal et al. 2020).

Climate indices (Table 3), derived from precipitation and temperature data were analyzed, as analytical tools for understanding the climate variability(Deniz, Toros & Incecik 2011) , to quantify the climate variability in the watershed . RClimDex program developed by Zhang & Yang (2004) was applied for indices calculation and understanding the climate variability in the Rangun Khola watershed.

Table 3: Climate indices considered for trend analysis

SN	ID	Indicator name	Definition	Units	Parameter
1	FD0	Frost days	Annual count of days when TN(daily minimum temp)<0 degrees C	days	Temperature
2	Su25	Summer days	Annual count of days when TX (daily max temp)> 25 degree C	days	Temperature
3	TR20	Tropical nights	Annual count of days when TN(daily minimum temp)>20 degrees C	days	Temperature
4	TN10p	cool nights	Percentage of days when TN<10th percentile	days	Temperature
5	TX10p	cool days	percentage of days when TX<10th percentile	days	Temperature
6	TN90p	warm nights	percentage of days when TN>90th percentile	days	Temperature
7	TX90p	warm days	percentage of days when TX>90th percentile	days	Temperature
8	TXx		Monthly Maximum of daily maximum temperature	Degree C	Temperature
9	TNx		Monthly Maximum of daily minimum temperature	Degree C	Temperature
10	R10	Number of heavy precipitations days	Annual count of days with ppt>10 mm	days	Precipitation
11	R20	Number of very heavy ppt days	Annual count of days with ppt>20 mm	days	Precipitation
12	CDD	Consecutive dry days	Maximum number of consecutive days with ppt<1mm	days	Precipitation
13	CWD	Consecutive wet days	Maximum number of consecutive days with ppt>=1mm	days	Precipitation
14	R95p	Very wet days	Annual total ppt when RR>95th percentile	mm	Precipitation
15	R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm	Precipitation
16	PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days where ppt>=1mm	mm	Precipitation

Source: Adapted from Zhang and Yang (2004)

The first nine indices in the table, Frost days (FD0), summer days (Su25), Tropical nights (TR20), Cool nights (TN10p) cool days (TX10p), warm nights (TN90p), and warm days (TX90p), monthly maximum of daily maximum temperature (TXx), and a monthly maximum of daily minimum temperature (TNx), are related to the temperature. The remaining seven, namely number of heavy precipitation days (R10), number of very heavy precipitation days (R20), number of extreme precipitation days (R50), consecutive dry days (CDD), consecutive wet days (CWD), very wet days (R95p), extremely wet days (R99p), annual total wet day precipitation (PRCPTOT), are related to precipitation.

3.2.4 Land Use Land Cover change trajectory analysis

Change in LULC plays an important role in groundwater recharge (Negi & Joshi 1996). The information about LULC was used to identify the linkage of land-use change with spring source change trends. The trajectory of LULC refers to the sequential transformation of land cover in the sampling unit over the period (Liu & Zhou 2004). Trajectory analysis of LULC, a recently emerging research methodology, was applied to detect time series based on the LULC change pathway at the pixel level (Ma et al. 2019). The pixel-based classified trajectory assessment helps in tracking the time-series change.

Time series (1990, 2000, 2010, and 2018) LULC imagery data, derived from Landsat TM 30 m image using public domain, object-based image analysis, prepared by ICIMOD(Uddin et al. 2021) were applied to assess land cover change in Rangun Khola watershed. To ensure consistency with the images from different years, all the LULC imagery were projected to WGS 1984 and pixel size of 30 x 30 m, commonly used resample remote sensing data (Ma et al. 2019). LULC layer of the Rangun Khola watershed was clipped from the National land cover database prepared by ICIMOD (ICIMOD 2013, 2014). The layers in a different projection system resolution were re-projected into the same form to acquire the overlapping layers for all the selected years.

The LULC types were reclassified into seven uniform land-use classes (with subsequent trajectory code), as Forest (1), Shrub (2), Grass (3), Agriculture (4), Riverbed, Bare land (5), Water (6), and Built-up (7) in the temporal slices (1990, 2000, 2010 & 2018) for each pixel. Continuous LULC dynamics of change trajectory was tracked by using the Raster calculator model of ArcGIS Pro version 2.7 (Esri 2020) on the LULC data layers. This method produced continuous LULC transformation over the four-decade period (1990-2018) in the form of codes, such as 1111, 1112….and so on until 6667.

3.2.4.1 Correcting LULC maps

Initial trajectory analysis, with the reprojected image, resulted in 457 combinations, where the fuzzy (231) and classification errors (58) identified were reviewed, verified and the correction was suggested (Table 4) based on the rationality rule (Liu & Zhou 2004).

Table 4: Suggested number of pixels corrected in the base map

Correction suggested	1990	2000	2010	2018
Forest	19	20	15	4
Shrub	4	0	0	0
Grass	10	10	10	3
Agriculture	2	21	30	25
Bare land	14	25	37	12
Grassland	46	21	19	19

The base map correction fine-tuned the classification and finally gave the decadal LULC change for the watershed in each land-use type (Figure 9). Change trajectory analysis corrected the inconsistencies and overestimation errors in the land cover map for Rangun Khola watershed. After correction of each base map and redoing, Trajectory Analysis condensed 450 combinations into 167 combinations with logical sequences.

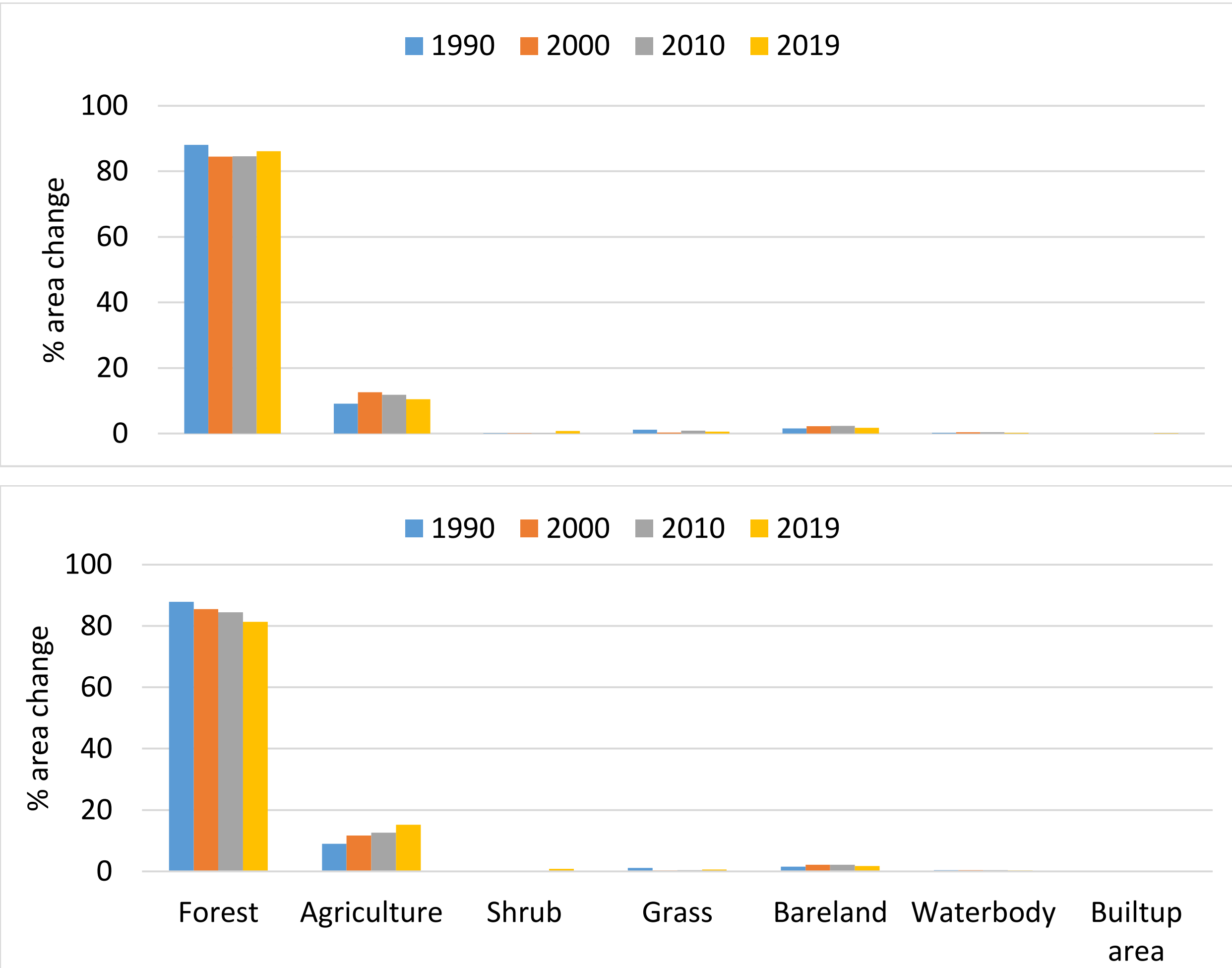


Figure 9: LULC changes in Rangun Khola watershed for 1990, 2000, 2010, and 2018 before (a) and after (b) correction

The accuracy of the corrected LULC map was assessed using the accuracy point and confusion matrix computation method to measure the difference between the independent reference map and the corrected LULC map. Based on the agreement between two maps, Kappa was calculated as the measure of similarity of the spatial allocation of the categories of the maps. The overall Kappa value of the corrected map was 0.727 as compared to 0.548 of the masked Base map, which also demonstrated the improved classification after correction (Table 5).

Table 5: Kappa value for Forest, Shrub, and Agriculture land-use class

Land cover type		Kappa
Forest	Masked 2018	0.83
	Corrected 2018	0.94
Agriculture	Masked 2018	0.67
	Corrected 2018	0.7
Shrub	Masked 2018	0.2
	Corrected 2018	0.4

Change trajectory analysis was done after map correction improved the accuracy of the Land cover Map. The trajectory change map was re-classified as vegetation improvement or degradation class and assessed from a vegetation change perspective (Figure 10). In the assessment process, forest was assigned 1 and other land-use classes assigned 2. Therefore, the vegetation change trajectory was determined as 1111- Intact Forest throughout the period, 1112- forest turned to other land-use types in 2018, 1122- forest degraded to other land-use types in 2010, 1222- forest degradation initiated in 2000.

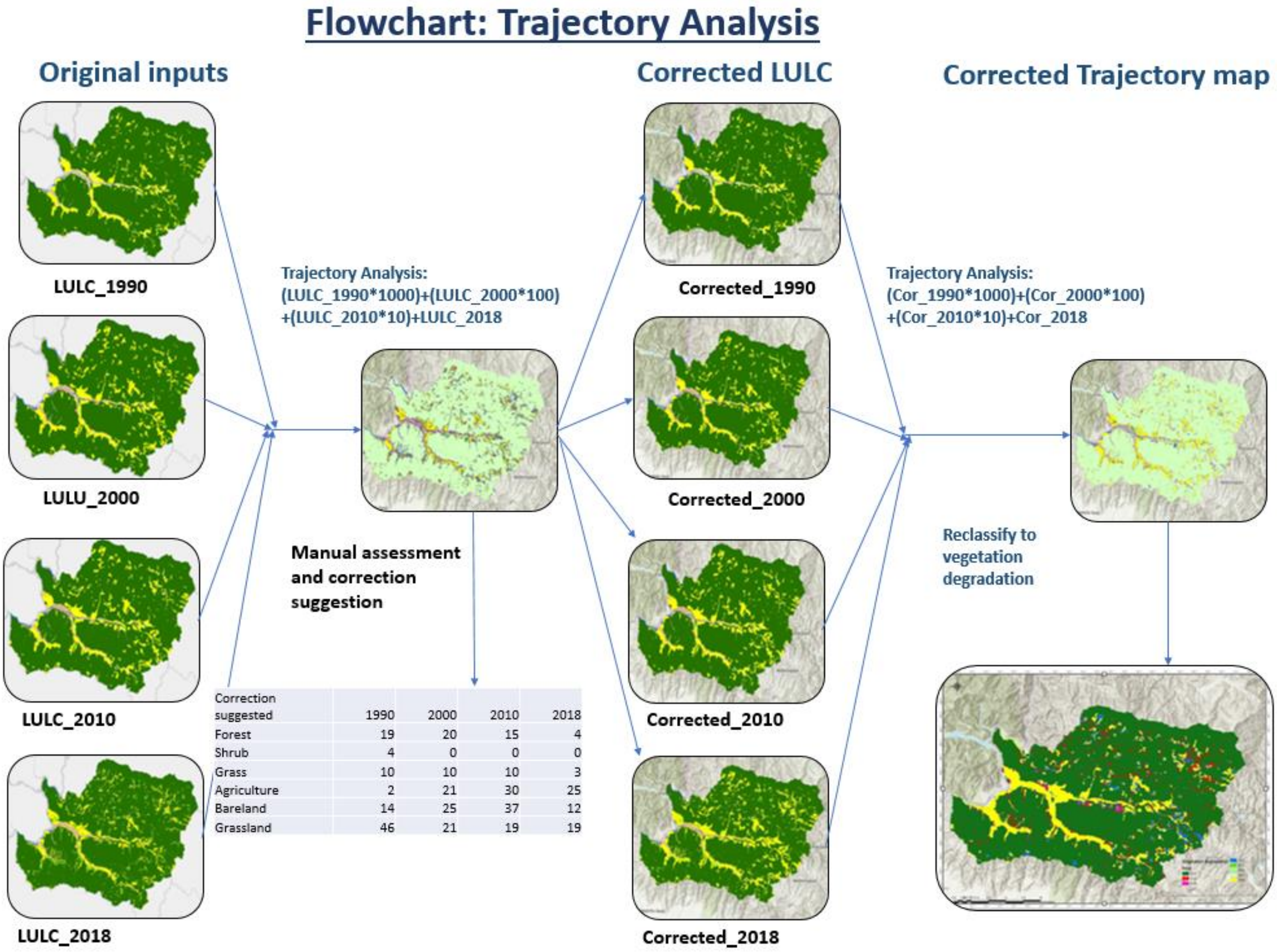


Figure 10: Trajectory analysis flow chart

3.2.5 Data validation

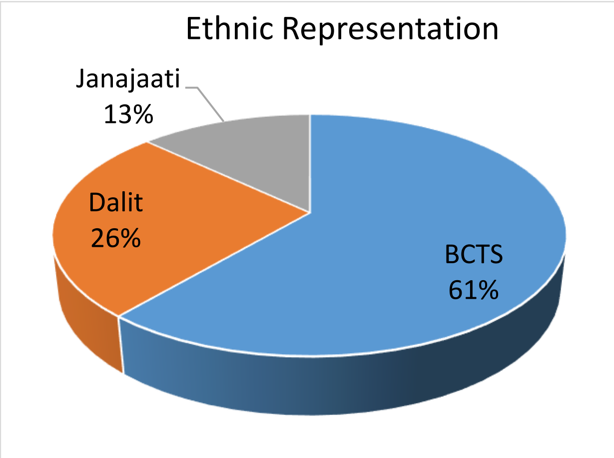
Spring source data was cross-validated with LULC (both 30* 30-pixel GIS-based LULC status in the immediate surroundings of the spring) data. A Chi-square test was performed to test the association between land use and spring flow trend. A logical association between changing climate and changing spring flow trend was assessed by graphical comparison. Road network and demographic setup data available from various sources were reviewed and applied for further assessment purposes using ArcGIS Pro version 2.7 (Esri) software. The socio-economic data of municipalities within the study area (e.g., road development, yearly budget allocation in different sectors, demographic status) were also used as supplementary data for the research purpose. Spring flow change and road or population density data were observed to examine the association between the anthropogenic drivers and their implication on spring flow change.

IV. RESULTS

4.1 Socioeconomic characteristics of Rangun Khola watershed

4.1.1 Household setup

A questionnaire survey conducted in 232 households selected by random sampling technique revealed that among people interviewed, 48% were male and 52% were female. Categorization of the respondents in the ethnic composition represented was 61% from Brahmin/Chhetri /Thakuri/Sanyasi (BCTS), 26% from Dalit, and 13% from Janajaati groups (Figure 11). The sample composition resembled the population census data and, therefore, the sample was considered as representative of the population.



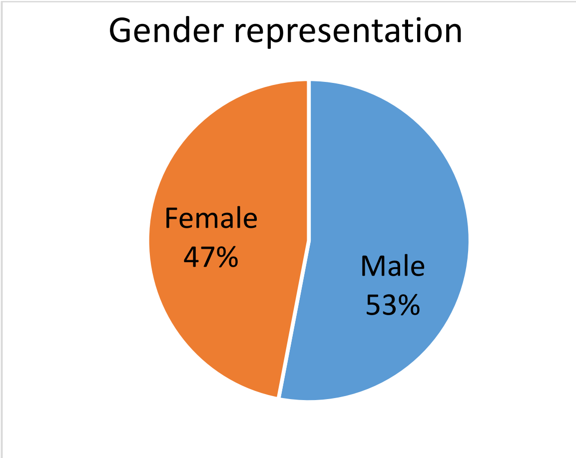


Figure 11: HH questionnaire survey respondent ethnic distribution

4.1.2 Livelihood dependency on water sources

Nearly 15% of respondents belong to landless households while 85% had access to land and are involved in agricultural practices. The livelihood of the community is mainly based on subsistence agriculture, where almost 82% of HH’s primary livelihood option was agriculture, followed by livestock rearing (3.9 %), daily wage (3.6%), remittance (2.3%), and seasonal migration (1.3%) (Table 6).

Table 6: Primary livelihood dependency of surveyed HHs

Primary options for livelihood	**HHs**
Agriculture	82.35%
Livestock rearing	3.92%
Daily wage	3.59%
Remittance	2.29%
Seasonal migration	1.31%

Households in the Rangun Khola watershed were prominently dependent on spring sources for day-to-day household water demand fulfilment. Piped water (76%), surface water (20%), and well water (4%) are the major water sources accessed by the community for household water demand fulfilment. Among the sources, primary dependency was reported on public spring sources as reported by almost 96% of the respondents. Piped water (76%), surface water (20%), and well (4%) are the major water sources accessed by the community for household water demand fulfilment. Among the sources, primary dependency was reported on public spring sources as reported by almost 96% of the respondents (Figure 12).

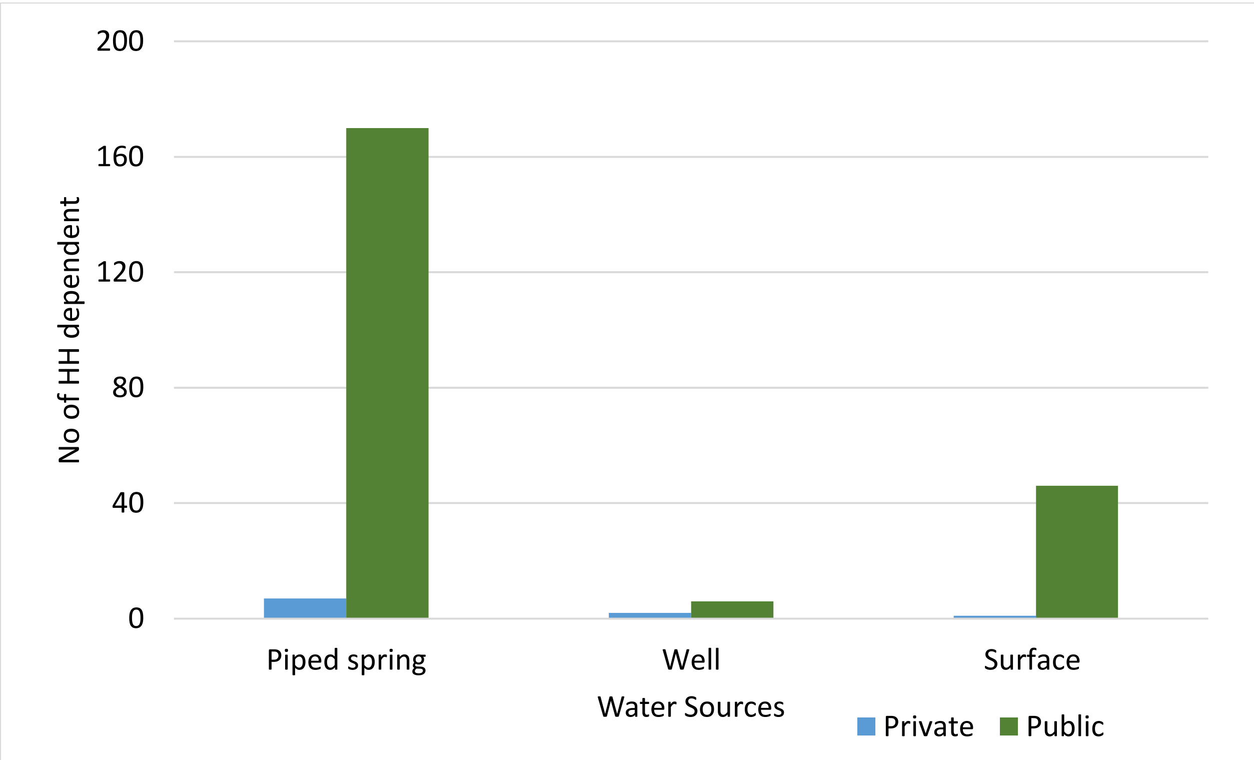


Figure 12: Water source dependency in Rangun Khola watershed

For agriculture, households were found prominently depending upon traditional water sources, such as rainwater (58%), irrigation canals from the river (55%), pond/lake (25%), and groundwater (3), while an insignificant portion was found using modern technique of solar lifting (Figure 13). Among these sources, almost 80% were seasonal sources as compared to 20% year round availability.

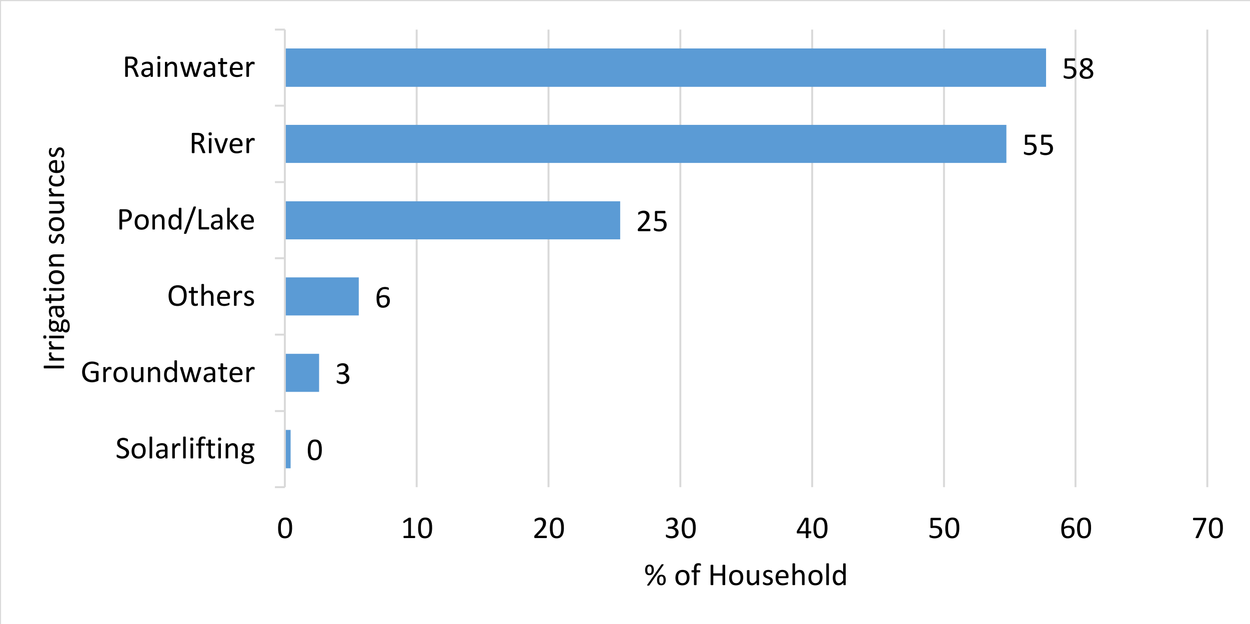


Figure 13: HH dependency for irrigation in Rangun Khola watershed

4.2 Springs sources in Rangun Khola watershed

4.2.1 Status of spring sources

A total of 1,122 spring sources were mapped, from Parashuram (743), Alital (364), and Jorayal (15) local administration units, within the Rangun Khola watershed. The spring density in the study area was 1.63 springs/km^2. Springs were located in the altitude range of 78 masl to 1820 masl within the Rangun Khola watershed, with 27% being located in the elevation lower than 500 m and above 1000 m while 46% were located in the range of 500 to 1000 m (Figure 15). Almost 50% of the springs were located on the northern slope, and 21% on the southern slope, while the rest were on the east (7%) and west (22%) facing slopes.

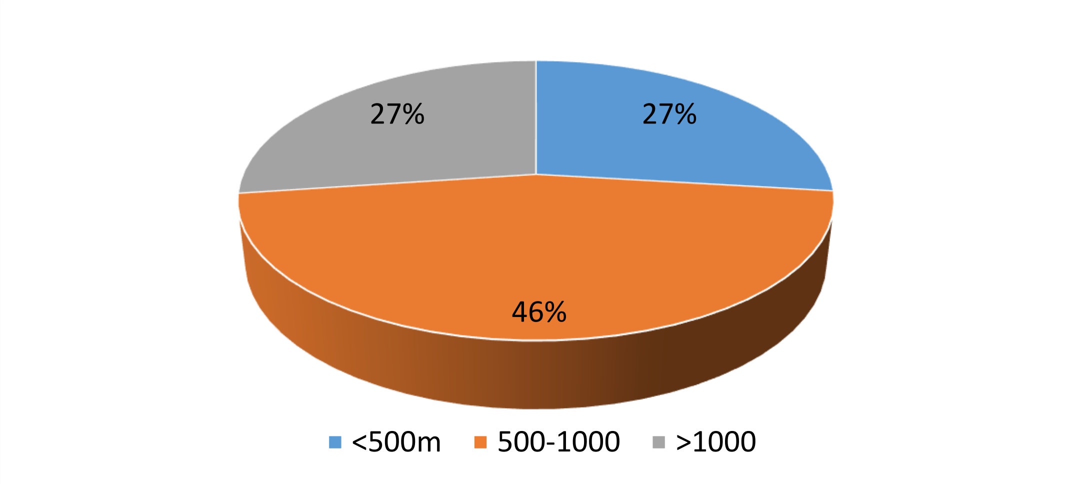


Figure 14: Spring distribution by elevation

Among total mapped springs, 90% were perennial and 10% were seasonal. Based on the type of springs, the most prominent (56%) were open springs, followed by the pond (19%), stone spout (13%), and the rest 12% were concrete tank (Figure 15)

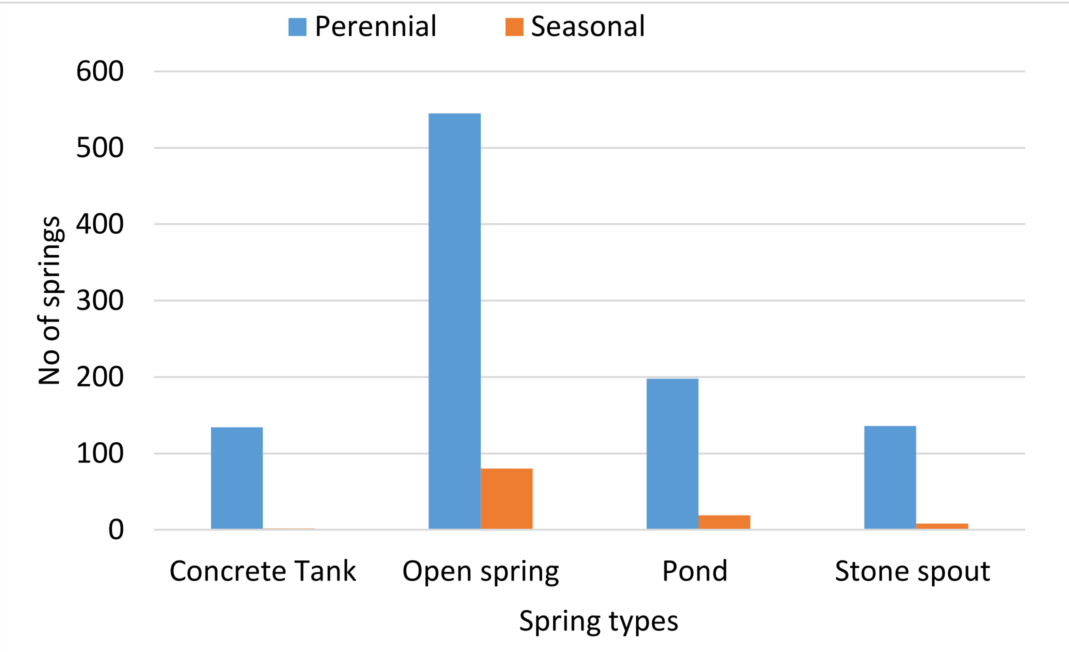


Figure 15: Distribution of 1,122 springs based on the spring type

In terms of slope, 43% of the springs were located on the land in lower slope range of 0 to 30 ^{0}, 27% in medium slope range of 30-45 ^{0}, 7% on moderate slope range of 45-60^{0} while 23% were in the steep slope of more than 60^{0} (Figure 16).

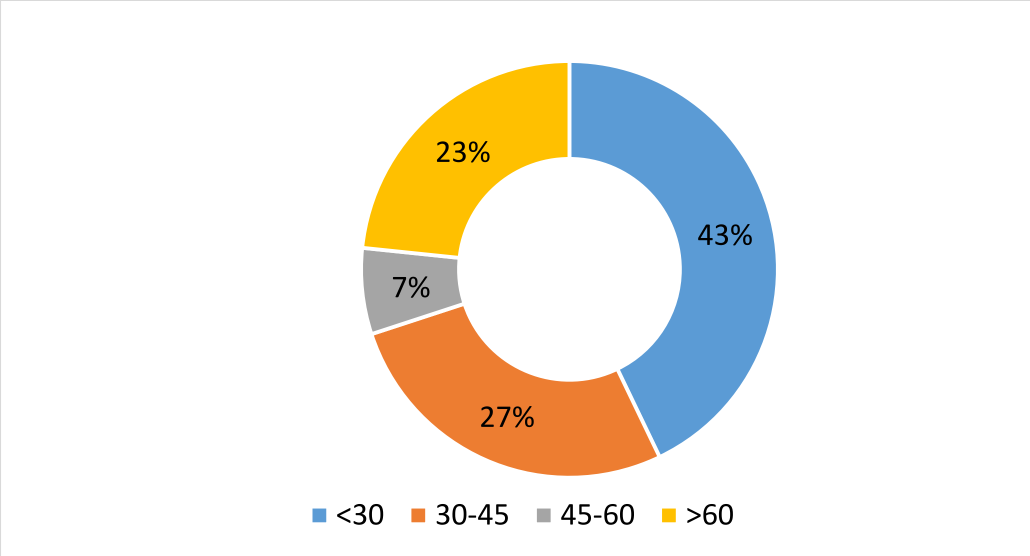


Figure 16: Spring distribution by the slope

Surrounding environment assessment conducted during spring source mapping revealed that almost half (46%) of the mapped springs were located within or in proximity to forest, followed by 27% laying close to agricultural land, 18% adjacent to shrub land, and 9% in the bare land area (Figure 17).

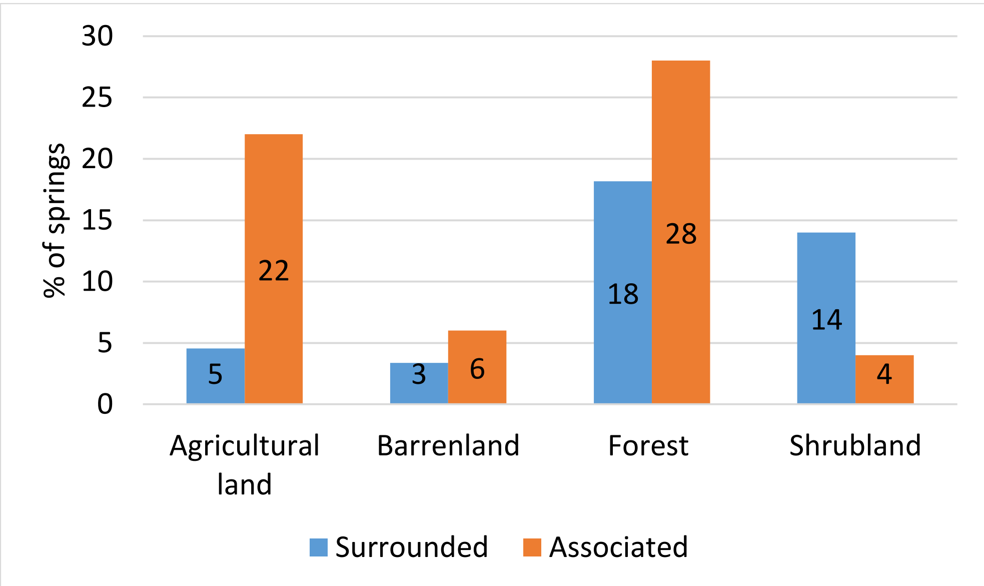


Figure 17: Spring distribution in different land-use proximity

Among the mapped springs, 71% of the springs were used for drinking and direct HH purpose, 9 % were supporting the community to fulfil an agricultural need while 20% of the mapped springs were not in direct use by the community, however, were indirectly serving the ecological needs (Figure

18). Among the unused springs, almost 90% were located far from the households or in the middle of the forest land and, therefore, inaccessible in normal circumstances.

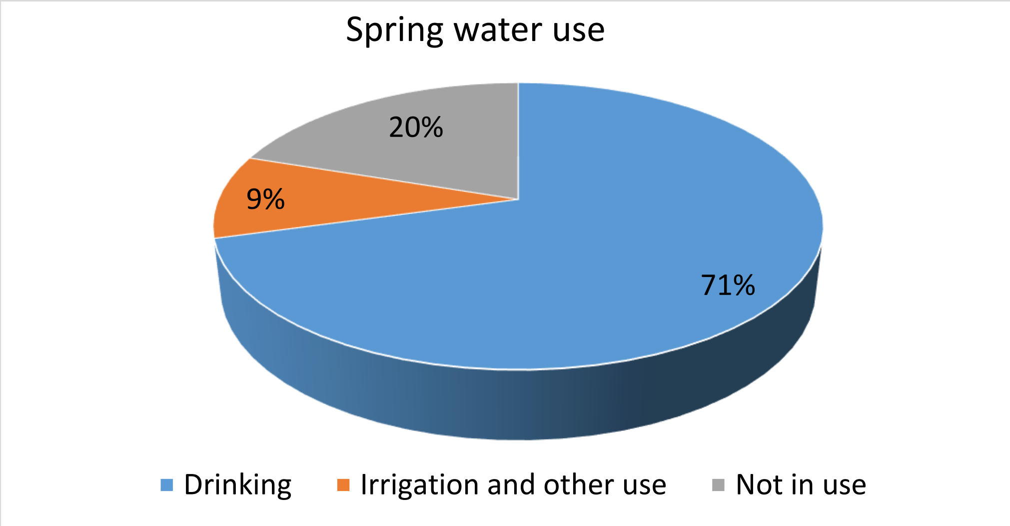


Figure 18**:** Spring dependency for various purposes

With an average spring dependency of 17 HH per spring, a large variation in household dependency (1 HH/spring to 300 HH per spring) was recorded in the Rangun Khola watershed. Among total mapped springs, almost 45% were supplying water to 0 to 10 HHs in the surrounding locality, 31% were serving 10 to 50 HH in proximity, while 4% were sustaining a cluster of more than 50 HHs in the surrounding area. Household dependency was unidentified for almost 20% of spring sources (Figure 19).

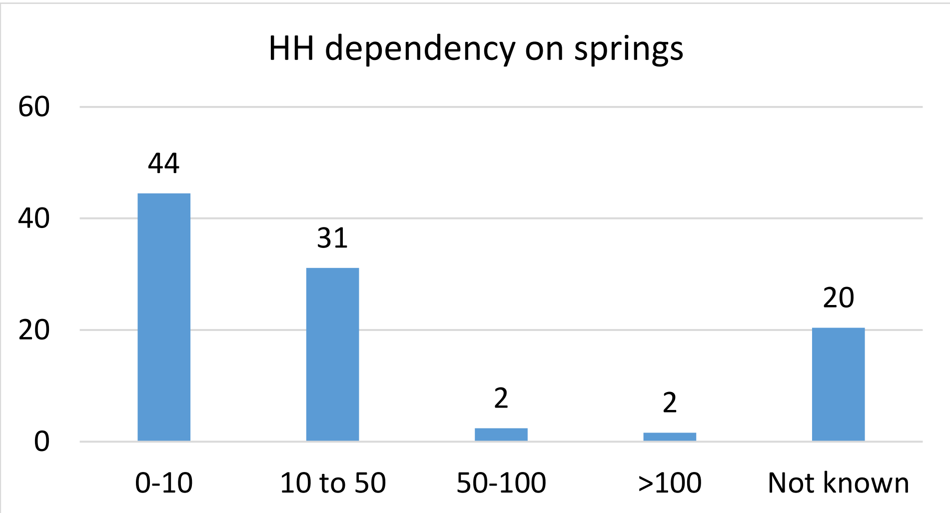


Figure 19: Range of HH dependency on spring sources

4.2.2 Spring flow trend

The spring discharge classifications done for the mapped springs revealed that the springs are in the flow range 0 to 3.33 l/s. The commonly encountered springs were low discharge springs less than 0.01 l/s, where 52% of springs have discharge in the range of 0.01-0.1 l/s and 19% of springs had discharge less than 0.01 l/s. Few of the high discharge springs (less than 2%) had a discharge of 1 to 10 l/s while almost 25% of the springs had a discharge of 0.1-1 l/s. There were 26 springs which had already dried up with no discharge at all (Table 7).

Table 7: The spring categorization in Rangun Khola watershed based on discharge

Discharge (l/s)	**Class**	**Grand Total**	**%**
>10,000	First	-	-
1,000-10,000	Second	-	-
100-1,000	Third	-	-
10-100	Fourth	-	-
1-10	Fifth	17	2
0.1-1	Sixth	277	25
0.01-0.1	Seventh	585	52
<0.01	Eighth	217	19
0		26	2
Grand Total		**1122**	**100**

Field measurement followed by recall methods applied during spring discharge assessment revealed that almost 72% of spring sources had shown a declining trend, whereas 23% were reported to be of constant flow, 3% showed increasing trend, while 2% were already dried up (Figure 20). Almost 2% of the spring sources were dried out in the watershed within the past 20 years. Among the dried springs, approximately 75% were reported to have dried out within the past 5 years, which confirmed the recent trend of declining spring sources in the Rangun Khola watershed.

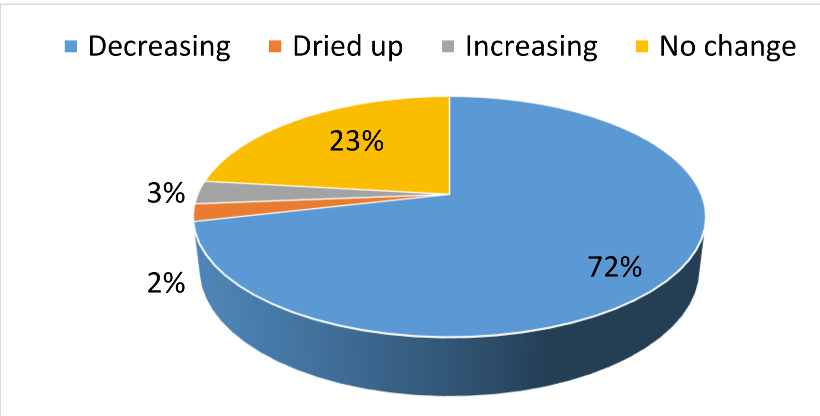


Figure 20: Status of spring sources in Rangun Khola watershed

Among the varied sources, almost two-thirds of every type of mapped spring in the Rangun Khola watershed were showing declining spring flow patterns, with some sources having dried up recently. In terms of orifice type, almost 80% of the open springs were showing a decreasing trend, followed by 67% of concrete tanks, 67% of ponds, and almost 62% of stone spout. Open spring sources showed more impact compared to the closed springs. In terms of seasonality, 10% of the seasonal springs recorded were already dried up while the remaining 86% were also showing a declining spring flow trend. Seasonal springs were showing a higher proportion of decreasing and drying up of springs as compared to the perennial springs with 70% showing a decreasing trend and 1% dried up. Almost 60% of springs located in every slope range were showing a declining trend in spring flow, with the highest being below 45^0 slope. Consequently, the springs serving smaller clusters of HH (54%) were threatened more than those supporting larger clusters (2.4%) (Table 8).

Table 8**:** Discharge trend by spring categories

Spring category		Decreasing	Dried up	Increasing	No change	Grand Total
Type of spring	Concrete tank	66	1	7	26	**12**
	Open spring	78	2	2	18	**56**
	Ponds	63	4	4	29	**19**
	Stone spout	59	3	3	35	**13**
Nature of spring	Perennial	70	1	3	26	**90**
	Seasonal	86	10	3	1	**10**
Slope	<30	75	4	2	19	**43**
	30-45	78	1	1	19	**27**
	45-60	68	1	8	23	**7**
	>60	57	2	6	35	**23**
Dependent HHs	0-10	72	3	4	22	**44**
	10 to 50	70	1	3	25	**31**
	50-100	56	0	4	41	**2**
	>100	61	0	6	33	**2**
	Not known	75	3	2	20	**20**
Surrounding environment	Disturbed	69	2	3	23	**96**
	Partially Disturbed	1	0	0	1	**2**
	Undisturbed	1	0	0	0	**2**
Grand Total		**800**	**26**	**36**	**260**	**1122**

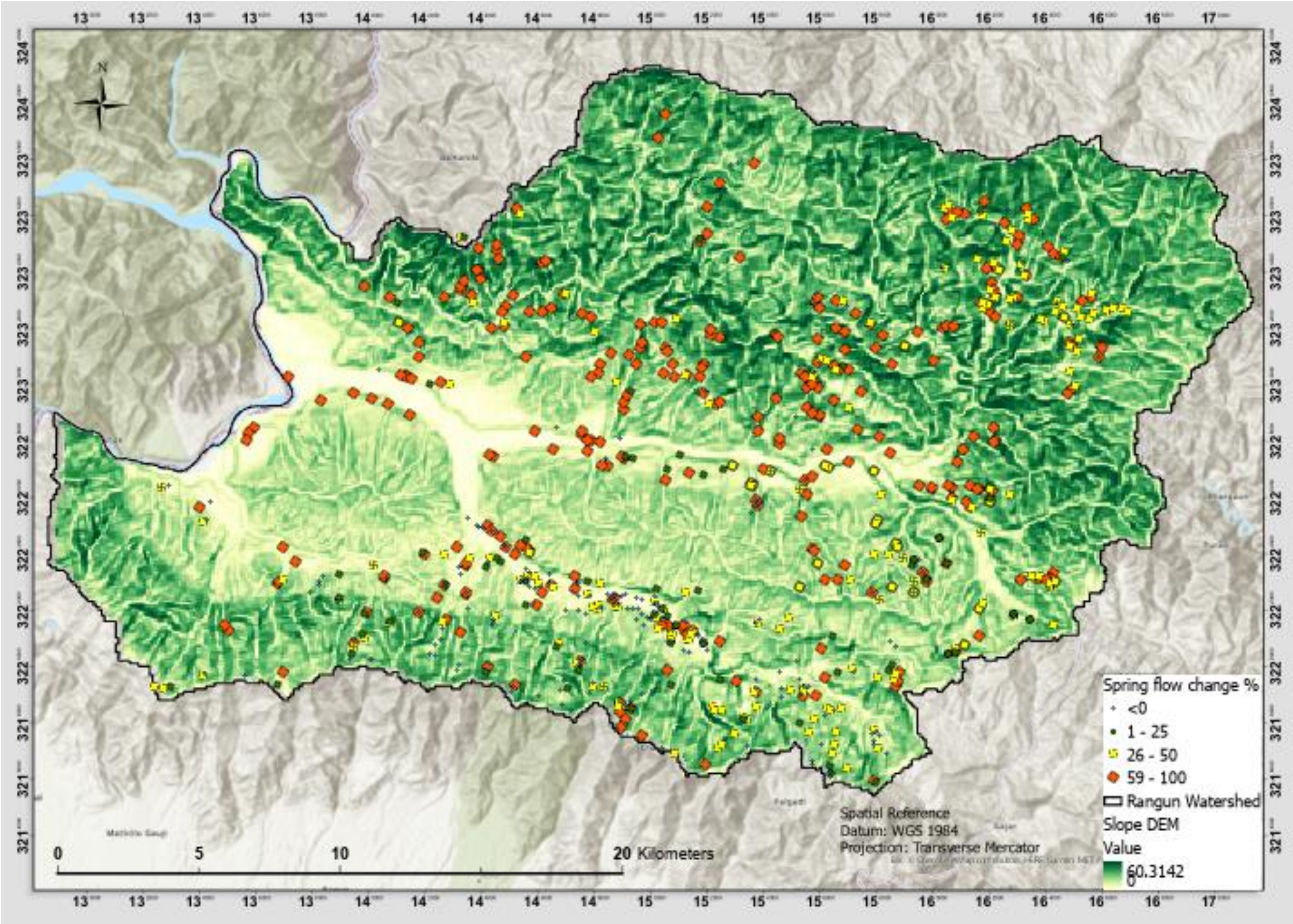


Figure 21**:** Map of Rangun Khola watershed with a high reduction in spring flow in higher elevation northern terrain

Extended spring sources assessment over time revealed that the long-term declining trend has been worsening in recent times. Even though 72% of springs were showing declining trends, the overall reduction was aggravated to 77% with the addition of springs with the constant flow also showing a declining trend in the past 5 years. The empirical data from these assessments was consistent with community perception, where almost 88% of the respondents reported declining spring water sources as a major implication of concern for HH livelihood (Table 9). This is also consistent with spring source mapping data depicting 77% decreasing water sources. Almost 70% HHs reported difficulties due to these drying water sources.

Table 9: Spring flow change pattern during different periods

Change	Trend					
	20 yrs.	10 yrs.	5 yrs.	Recent	Total	%
No change	202				202	18
Dried up	6	1	7	12	26	2.32
Decreasing	509		291	58	858	76.47
Increasing	25	2	9		36	3.21

4.2.3 Changing spring flow dynamics

With prominent dependency on public water sources in the Rangun Khola watershed, almost 82% of HH indicated there were declining water sources and consequently there were aggravating water scarcity issues in the community (Figure 22).

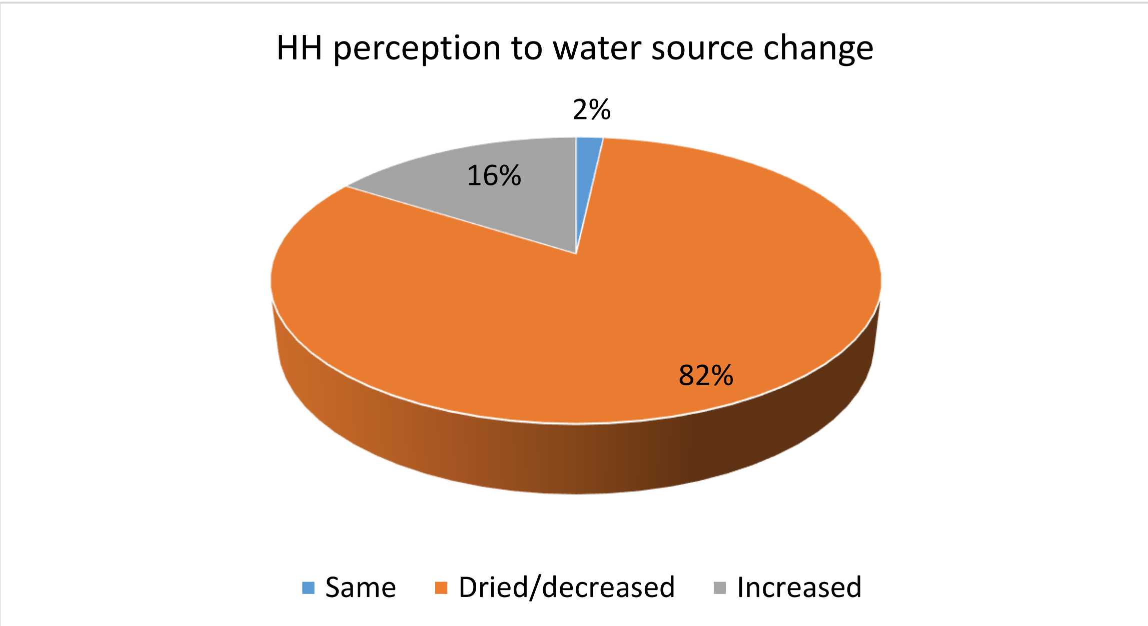


Figure 22**:** HH perception of changing water sources

Detailed assessment of spring flow rate (l/s) sheds light on temporal variability in discharge over time revealed that the drying spring sources are evident in the Rangun Khola watershed. The flow rate has drastically changed as compared past 20 years. The number of dried spring sources has increased significantly in recent 10 years. Ten years ago, there was only one spring reported as dried; however, that figure has now increased to 26 after 10 years. Therefore, this drying of springs has increased significantly in the recent 5 years (Figure 23).

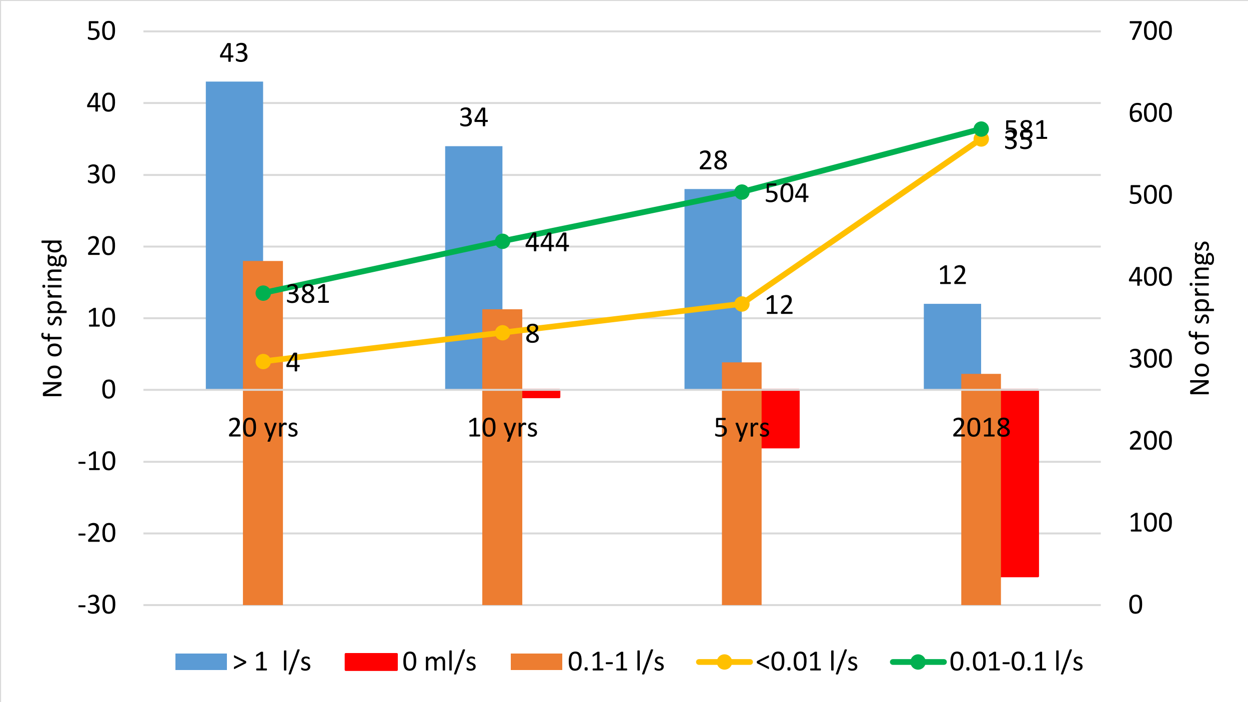


Figure 23**:** Number of springs with a flow rate in different time series, indicating decreasing number of high flow springs (>0.1 l/s)

Moreover, as evident in the Figure 24 comparative maps of spring flow rate, the density of springs with high flow rates has reduced significantly, while the group of springs with lower flow rates has increased. Previously, 43 springs with flow rate >1 l/s 20 years ago have reduced to 12, while 420 springs with flow rate 0.1 l/s have now reduced to 282. In addition, 381 springs with flow rate of 10-100 ml/s have increased to 581, and even springs with <10 ml/s have increased from 4 to 35 within 20 years with concurrent increment in several springs with a flow rate less than 0.1 l/s.

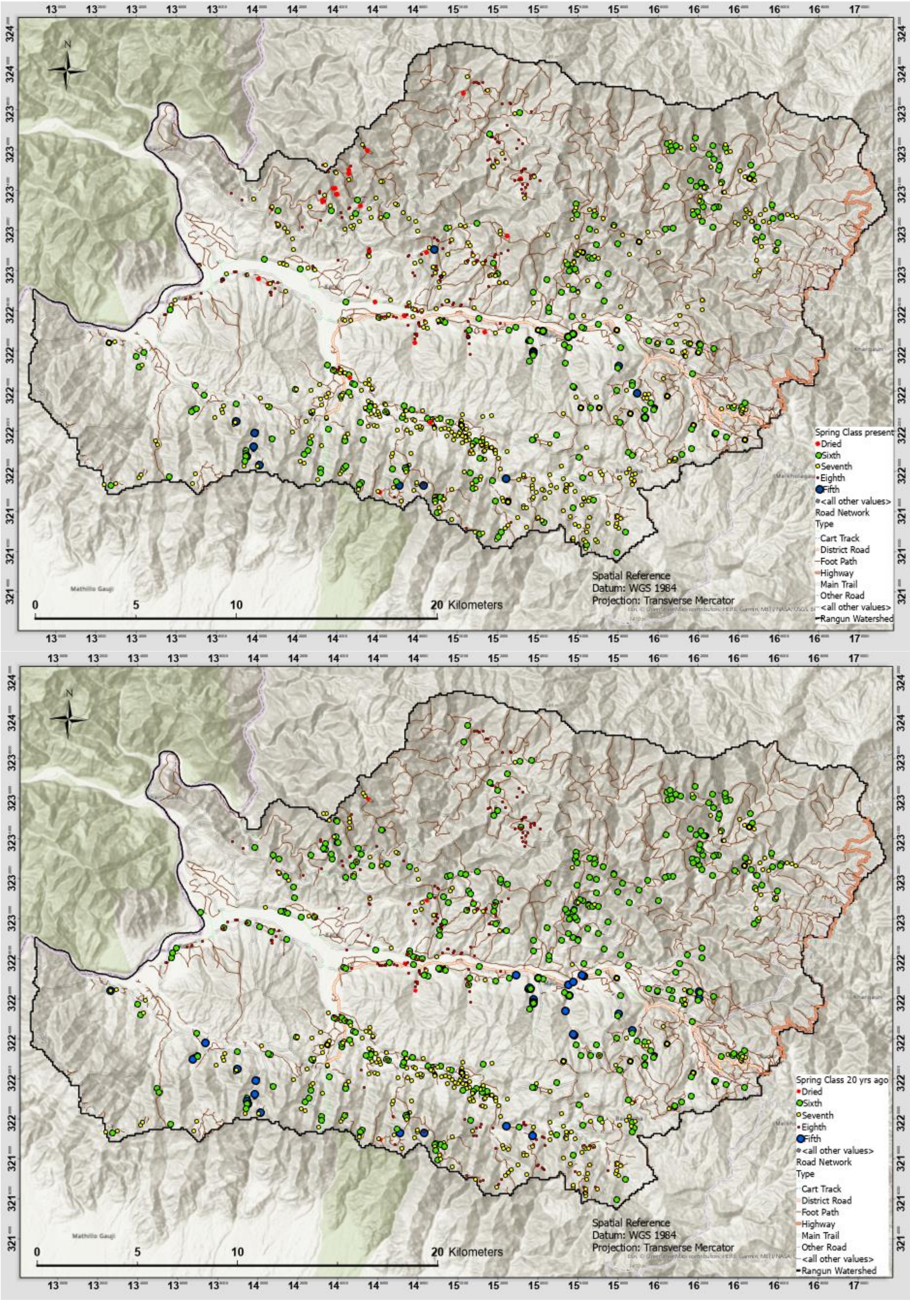


Figure 24: Spring class change in 20 years based on spring source mapping and community recall method

4.3 LULC change and its implication on water resources

4.3.1 LULC change pattern in Rangun Khola watershed

The four land use maps (1990, 2000. 2010 & 2018) were studied to understand the LULC change situation and detect the spatiotemporal changes in the Rangun watershed using the trajectory analysis method. The LULC analysis showed that almost 70 km^2 area accounting for 10% area of the Rangun Khola watershed has undergone land cover changes, while almost 90% of the area was unchanged in 20 years (Table 10). Observing the trend in land-use change, 88% of the forest area was reduced to 81% with subsequent augmentation of agricultural land from 9% to 15%, which were the prominent shifts in land cover moving from 1990 to 2018.

Table 10: LULC change between 1990-2018

	2018								
1990	Land use type	Forest	Shrub	Grassland	Agriculture	Barren land	Water body	other	Total
	Forest	80.68	0.34	0.47	6.23	0.13	0.02	0.01	87.88
	Shrub	0.02	0		0.01				0.04
	Grassland	0.01	0.01	0.01	0.66	0.46	0.01	0.01	1.16
	Agriculture	0.44	0.43	0.08	7.9	0.15	0	0.01	9.03
	Barren land	0.1	0	0	0.39	0.96	0.03	0.01	1.5
	Water body	0.04		0	0.02	0.09	0.24	0	0.4
	Grand Total	81.31	0.78	0.57	15.21	1.79	0.3	0.04	100

The LULC trajectory analysis verified the subsequent incremental increase of agricultural land with a corresponding decline in forest cover and associated alteration in another landform. The forest land conversion to agricultural land by 6.23% (42.79 km^2) was the prominent transformation followed by 1.08% (7 km^2) accumulation from other landforms. In the case of the agricultural land expansion by 7.31%, almost 85% is credited to deforestation followed by less than 1% transformation of other landforms (Figure 25).

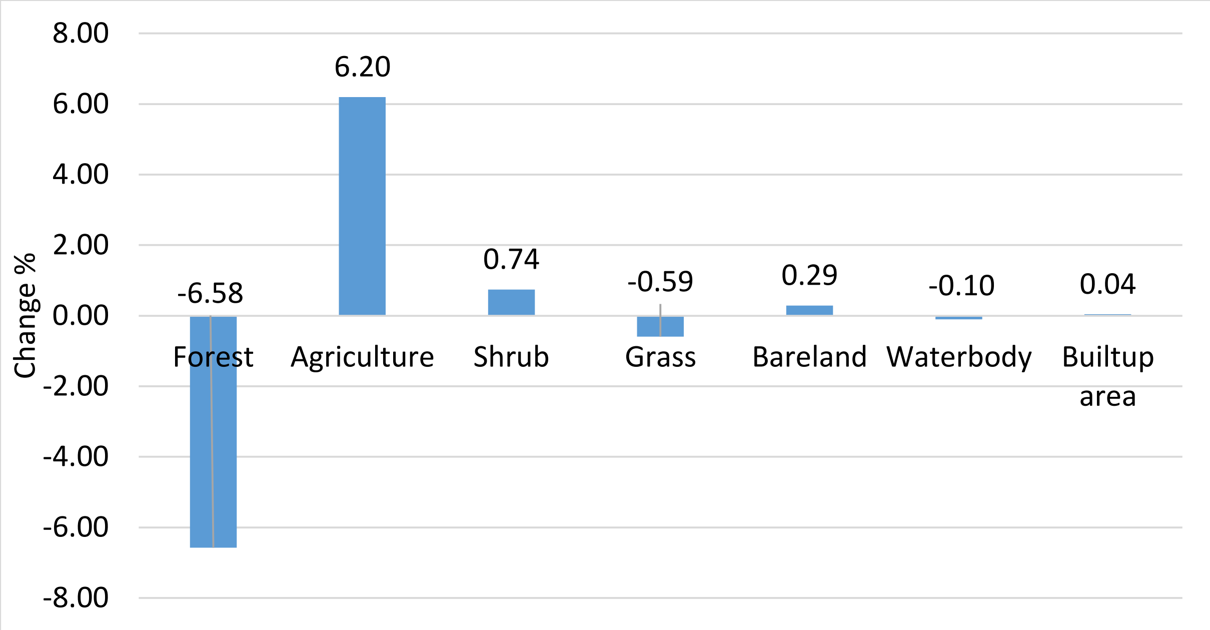


Figure 25: LULC change percentage in Rangun Khola watershed between 1990-2018

Trajectory analysis with LULC maps of 1990, 2000, 2010, 2018, and reclassification of total change into forest degradation and improvement category (Figure 26) revealed that within 29 years, total forest cover reduction was 7.2% (49.5 km^2) compared to negligible upsurge by 0.62% (6.5 km^2) with resultant 6.6% (45.3 km^2) of forest degradation in Rangun Khola watershed. Among the transformations, the 1990-2000 decade experienced prominent forest clearance of 23.3 km^2 area, with 8.9 km^2 deforestation during 2000-2010, and 17.2 km^2 during the recent decade (2010-2018) (Table 11). Among total forest degradation during the 20 years period, almost 87% was credited to agricultural expansion.

Table 11: LULC trajectory of change between 1990 to 2018

SN	Change trajectory	Area km^2	%
1	Unchanged forest	554.3	80.68
2	Forest Degradation 2000	23.3	3.39
3	Forest Degradation 2010	8.7	1.27
4	Forest Degradation 2018	17.5	2.54
5	Forest Improvement 1990	0.7	0.10
6	Forest Improvement2000	1.4	0.21
7	Forest Improvement2018	2.1	0.31
8	Unchanged other land use	79	11.50
	Total	687	

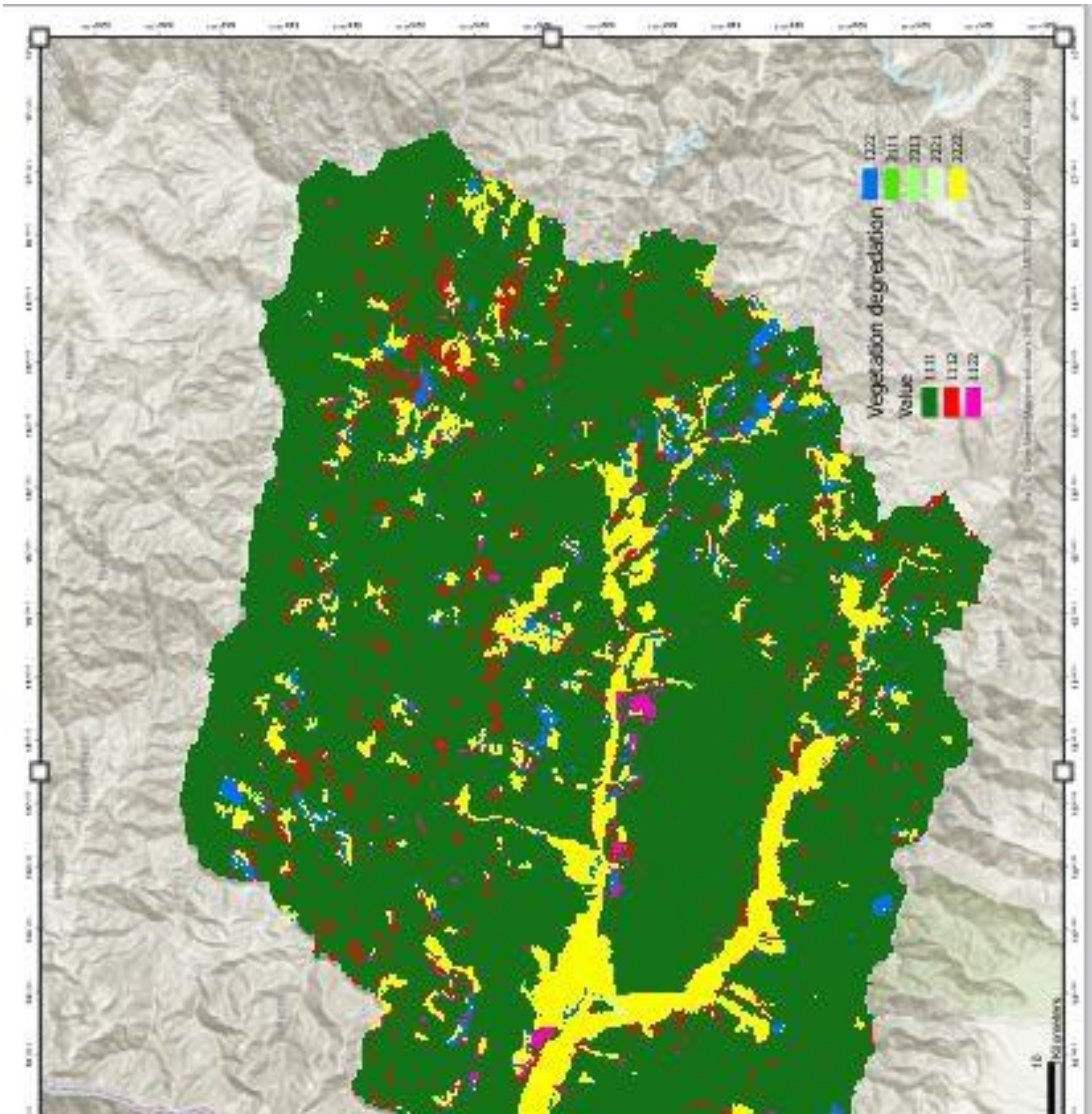


Figure 26: LULC trajectory map of Rangun Khola watershed (1990-2018)

4.3.2 LULC change and changing spring resources

Chi-square test done for changing spring discharge and LULC trajectory change accessed using 30 m by 30 m land use map did not show any significant association between changing LULC and declining spring flow trend. However, the incorporation of the immediate land use status of each spring revealed that LULC disturbance has a direct implication on the quality of springs (Figure 27). The LULC map (Figure 27) illustrates that most of the springs in the southern belt showed less than 25% reduction in spring flow, whereas reduction in the northern belt flows was more than 50%.

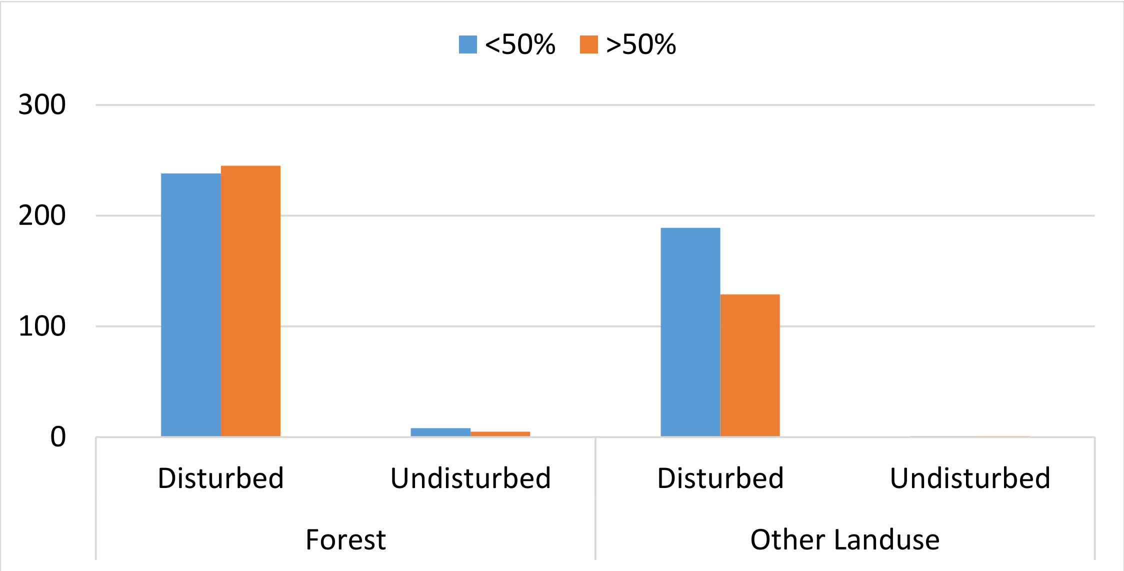


Figure 27: Spring source distribution and their changing flow rate

The map depicting forest degradation over three decades in Rangun Khola watershed and springs located in the disturbed environments (Figure 28) shows a significant reduction in flow trend as compared to springs in an undisturbed environment. Spring flow and surrounding land cover change showed a significant association.

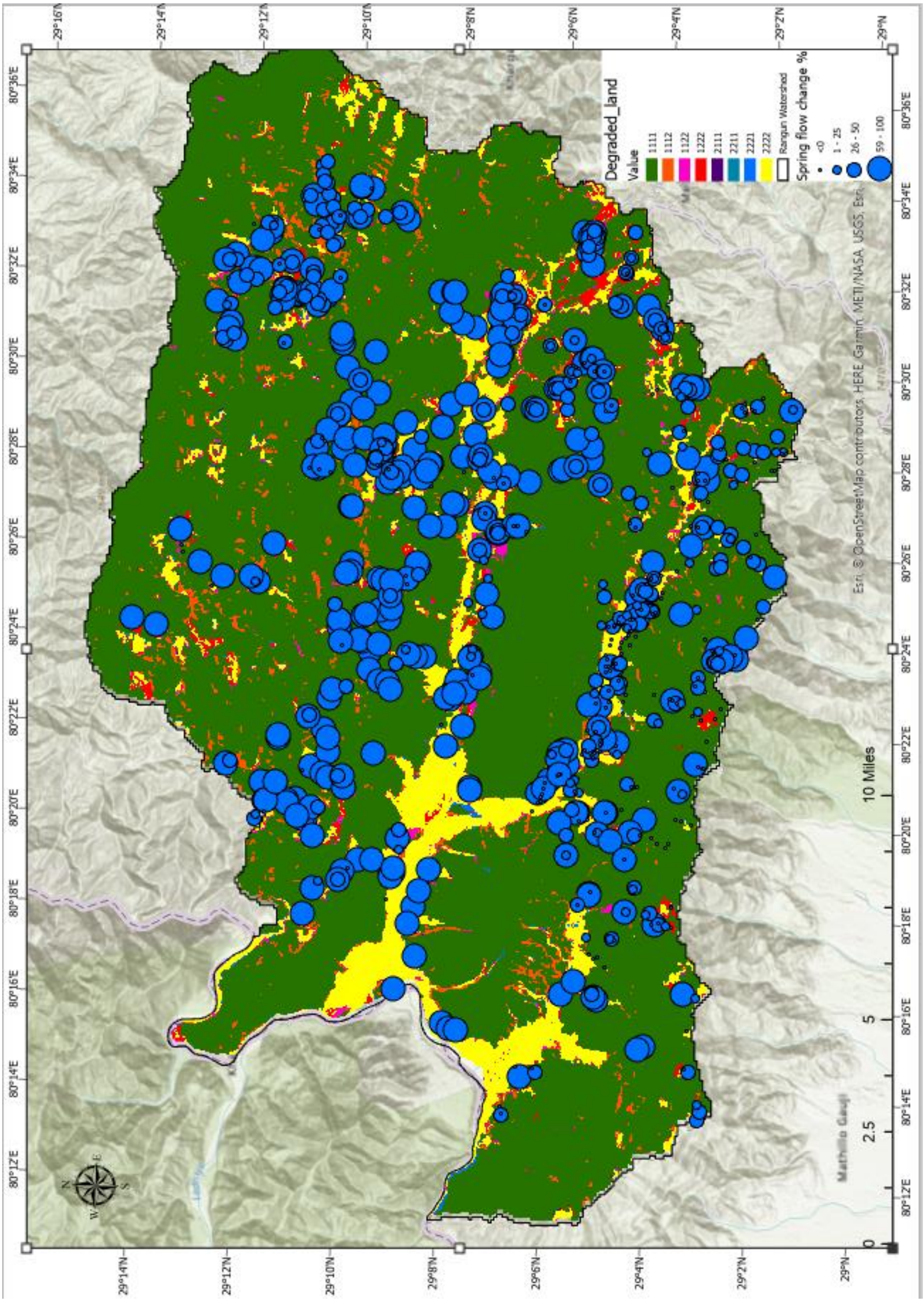


Figure 28: Spring flow decrease pattern overlayed on the land-use trajectory map

4.4 Climate change assessment

4.4.1 Community perception on changing climate

Almost 40% of the respondents reported that they are aware of climate change issues. Among the total HHs reporting familiarity with the issue, detailed questions revealed that radio/TV was the primary source of information (65%), followed by training/workshop related events (51%), newspaper (36%), educational institutions (35%), and friends (30%) (Figure 29).

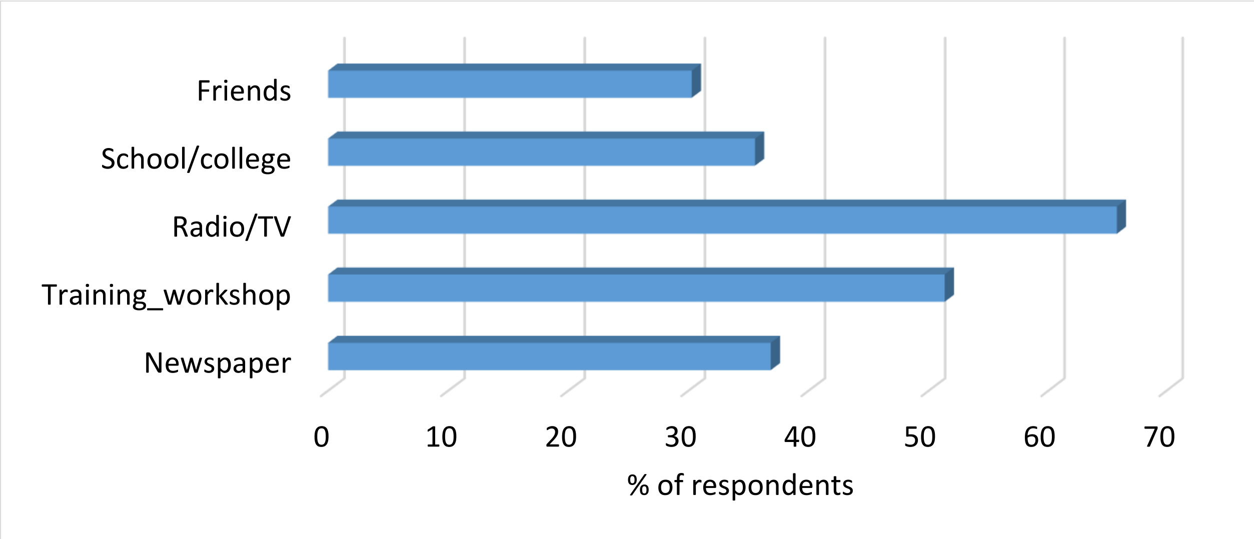


Figure 29: Source of information on climate change issues

During the investigation of HH perceptions about ongoing changes in climatic condition, more than 80% of HHs reported that the water availability, at source as well as productive water availability in the form of precipitation, has decreased significantly as compared to the past decade. Almost 75% of the responding households stated that increasing higher temperatures and consequent upsurge of drought and weather-related natural calamities (e.g., flood, landslide) are an increasing trend (Figure 30).

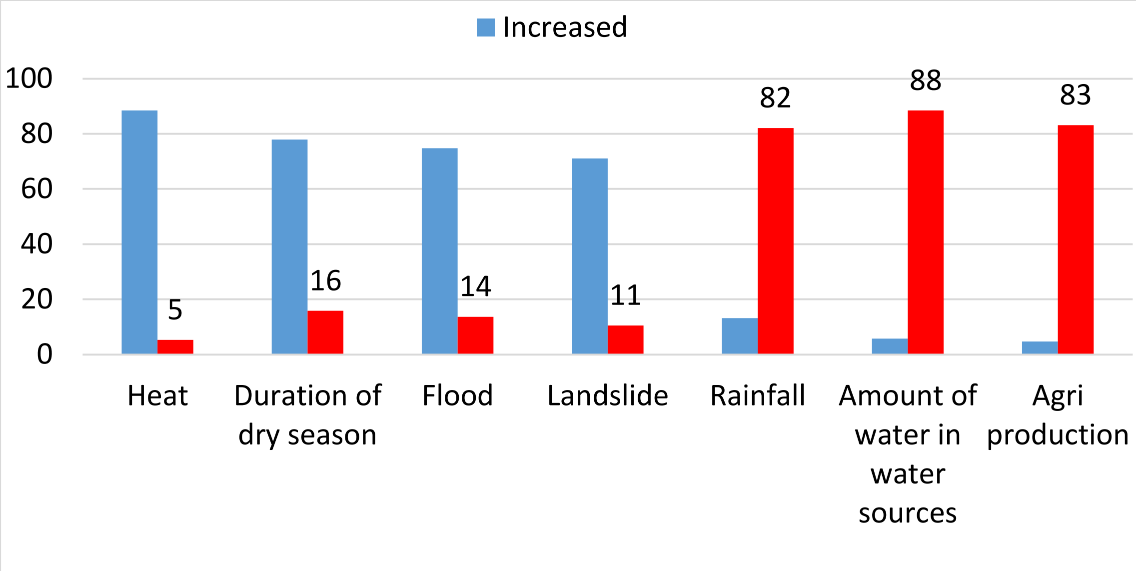


Figure 30: Community perceptions of changing climate as compared to 10 years and now

4.4.2 Climatic trend analysis

An analysis of rainfall, temperature, evapotranspiration, and net precipitation data from the Department of Hydro Meteorology (DHM) revealed variation in climate patterns in the Rangun Khola watershed over the past 38 years. The summary of trends in major climate parameters is shown in Table 12. The result indicates that among all the parameters assessed, precipitation showed a decreasing trend, whereas temperature and consequent evapotranspiration showed an increasing trend. Among the trends, the change was significant at 95% CL for temperature (TMax and T annual), evapotranspiration, and net precipitation, while for precipitation and minimum temperature trends were not statistically significant.

Table 12: Trends and statistical significance for climatic parameters of Dadeldhura station

Parameter	Definition	Mean	Std. Deviation	Slope	z	p-value
T max	Maximum temperature	21.1	1.3	0.1	5.6041	0.00*
T min	Minimum temperature	11.4	0.5	0	0.33788	0.74
T An	Average Annual Temperature	16.2	0.7	0.1	5.3944	0.00*
Rainfall	Total annual precipitation	1385.9	268.9	-3.2	-0.75431	0.45
Net ppt	Net precipitation	240.8	298	-10.7	-2.3635	0.02*
ET	Evapotranspiration	1152.1	100	7.6	4.1187	0.00*

(*) $P<0.05$

a) Precipitation trends

The 38-year precipitation pattern shows a slightly decreasing trend in annual precipitation (-3.15 mm/yr); however, the trend was not significant statistically (Table 13). Among the four seasons, the declining trend was comparatively higher in pre-monsoon (-2.29 mm/yr) and winter season (-1.05 mm/yr) as compared to monsoon (0.41 mm/yr) and post-monsoon (-0.16 mm/yr). The pre-monsoon and winter rain plays a significant role in agricultural production, which may explain community perceptions of a decline in precipitation since farmers rely on dependable rainfall. Even though the decline was not significant, the trend may be indicative of changing rainfall patterns in the watershed.

Table 13: Seasonal precipitation pattern

Parameter	Annual	Pre-monsoon	Monsoon	Post-Monsoon	Winter
Minimum	781.1	17.4	604.5	0	19.5
Maximum	2066.4	377.9	1477	397.4	270.9
Average	1385.9	197.8	1018.9	48.9	127.9
Std. deviation	268.9	86.8	207.4	84.9	66.5
Precipitation trend (mm/yr)	-3.02	-2.29	0.41	-0.16	-1.05

Although the total precipitation did not show any significant trend, a detailed assessment of the number of rainy days revealed that the total number of rainy days with rainfall less than 1mm rainfall increased (0.33 day/yr) while more than 1 mm significantly decreased (-0.29 day/yr) (Figure 31). Similarly, an insignificant reduction trend of -0.19 days/yr for 10 mm and 25 mm rainfall in the watershed was also noticed. Therefore, the data demonstrate that even though total precipitation did not change, the rainfall pattern changed significantly.

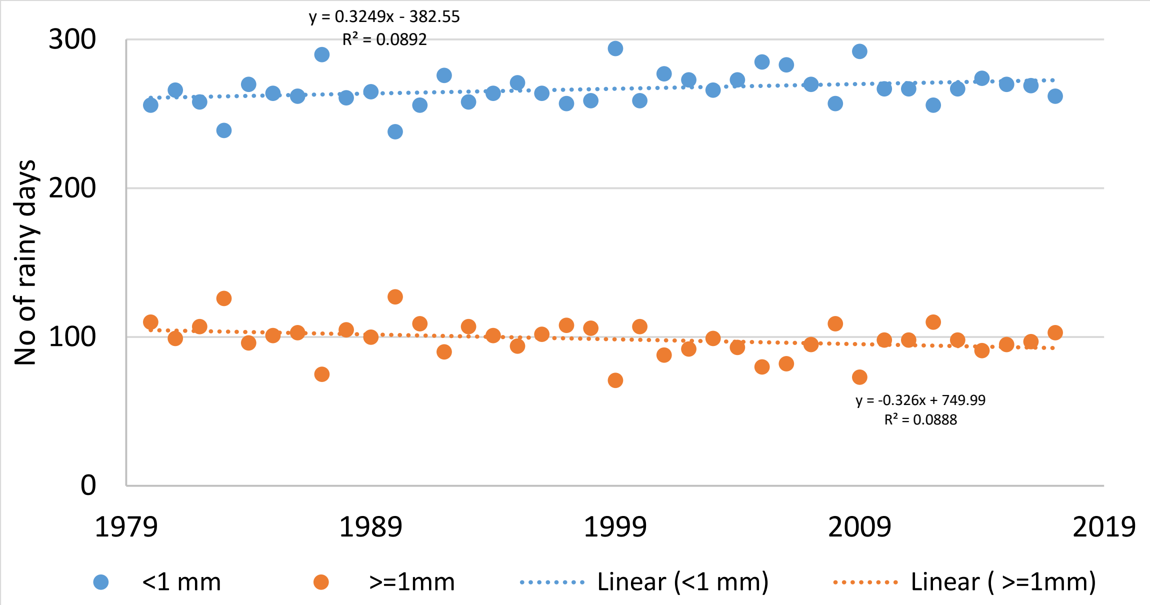


Figure 31: Trend of number of rainy days (<1mm & >=1 mm rainfall)

The precipitation indices indicated that total precipitation (PRCPTOT) along with the number of days with 10mm, 20 mm, and consecutive dry days (CDD) are decreasing slightly. In contrast, a slight increment in consecutive wet days (CWD) and a significant increment in extremely wet day precipitation (R99p) (3.2 mm/yr.), is depicting the altered magnitude and frequency of the wet days (Table 14).

Table 14: Summary of precipitation indices trends in the study area

Code	Definition	Slope	z	p-value
R10	Heavy precipitation days (days)	-0.2	-1.7	0.1
R20	Very heavy precipitation days (days)	-0.2	-1.6	0.1
CWD	Consecutive wet days (days)	0.3	0.0	1.0
CDD	Consecutive dry days (days)	-0.1	0.9	0.4
R95p	Very wet days precipitation (mm)	3.6	1.0	0.3
R99p	Extremely wet days precipitation (mm)	3.2	2.0	0.0
PRCPTOT	Annual total wet days precipitation (mm)	-3.2	-0.8	0.5

b) Temperature trend

The trend analysis for temperature pattern for Dadeldhura station revealed that with a significant increase in maximum temperature at 0.1 ^{0}C/yr consequent annual temperature increase at 0.05 ^{0}C/yr and insignificant though slightly increasing trend of minimum temperature (0.0012 ^{o}C/yr), the station has recorded overall increasing trend in temperature parameters (Figure 32).

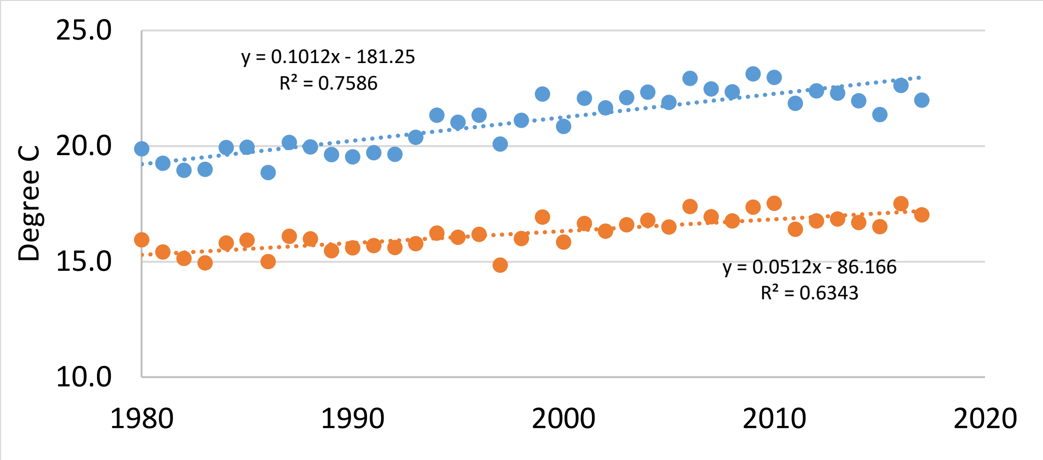


Figure 32: Significantly increasing temperature (Blue-Maximum, Orange-Annual) trend, (1980-2018) Dadeldhura station

A further step assessment of temperature indices (Table 15) indicated that frost days (FD0), cool nights (TN10p), and warm nights (TN90p) are showing a slightly decreasing trend. There is a consequent significant increase in a monthly maximum of daily temperature (TXx) by 0.07 ^{0}C/yr, monthly maximum of daily minimum temperature (TNx) by 0.097 ^{0}C/yr, summer days (Su25) by 2.92days/yr, warm days (TX90p) by 0.75 days/yr, and significantly decreasing cool days (TX10p) by 0.44 day/yr. These values of the overall increasing trend in maximum and minimum daily temperature along with aggregating number of summer and warmers days and consequential lessening cool days accumulatively validate the warming temperature in the adjoining locality.

Table 15: Summary of trends in temperature indices in the study area

Indices	Definition	Slope	z	p-value
FD0	Frost days (days)	0.0	-0.7	0.5
Su25	Summer days (days)	2.9	6.4	0*
TR20	Tropical nights(days)	0.0	0.7	0.5
TN10p	Cool nights (days)	-0.1	-1.3	0.2
TX10p	Cool days (days)	-0.4	-5.0	0*
TN90p	Warm nights (days)	0.0	-0.3	0.7
TX90p	Warm days (days)	0.7	5.0	0*
TXx	Monthly Maximum of daily max temp	0.1	2.3	0.021*
TNx	Monthly Maximum of daily min temp	0.1	2.9	0.003*
TMax	Maximum temperature	0.1	5.6	0*
TMin	Minimum temperature	0.0	0.3	0.7
T Ann	Average Annual Temperature	0.1	5.4	0*

4.4.3 Changing climatic pattern and water availability

The significantly increasing temperature and slightly decreasing precipitation trend have consequently impacted the evapotranspiration and resultant net precipitation trend in the study area. The potential evapotranspiration trend shows a significant upsurge at a rate of 7.6 mm/yr. This attenuated evapotranspiration has diminished the availability of surface and subsurface flow to supplement groundwater in the locality, which was validated by the significantly falling net precipitation at the rate of 10 mm/yr (Figure 33). The seasonal trend analysis done with net precipitation data indicated that the overall trend for all four seasons was declining with a significant reduction of net precipitation in the post-monsoon season (Figure 34).

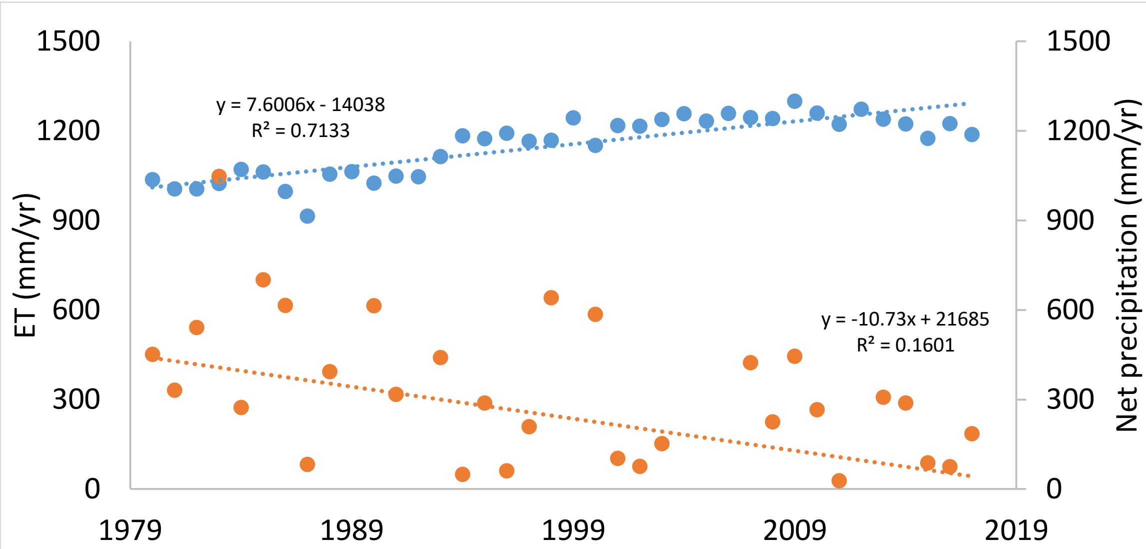


Figure 33: Evapotranspiration (blue) and net precipitation (orange) trend for past 38 years

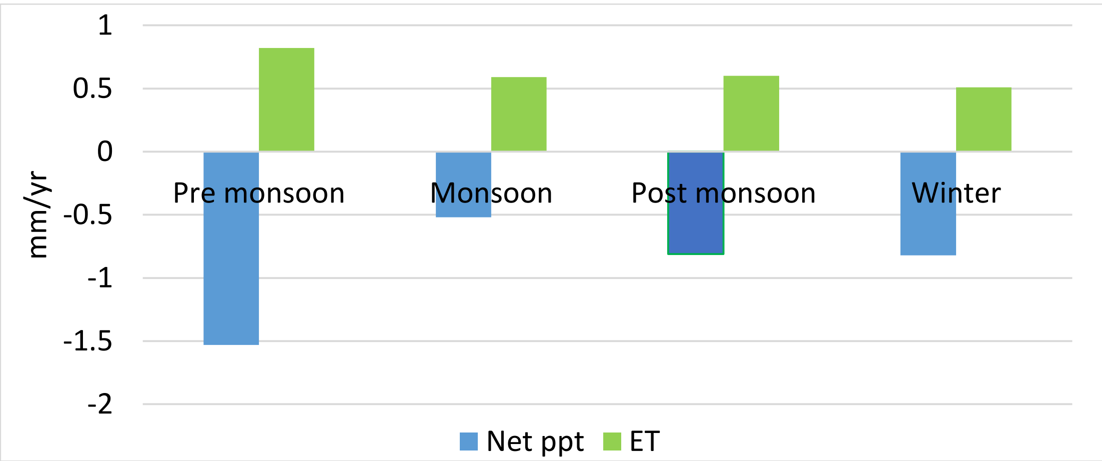
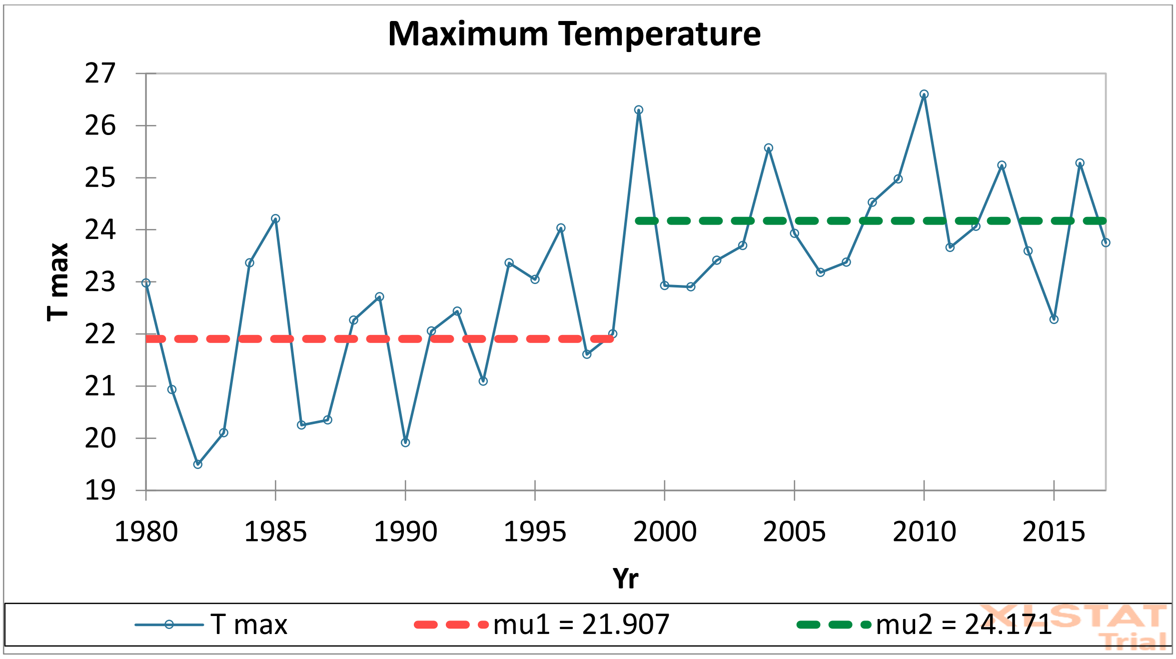


Figure 34: Evapotranspiration and net precipitation seasonal trend comparison (1980-2018) for Dadeldhura Station

A Pettit test indicated 1998 as a shifting year (Figure 35). Before and after trend analysis indicated that maximum temperature shows a significant increasing trend in both halves. This significantly increasing trend over the past 20 years was likely affecting community perception about climate change, which would have been further influenced by the spring flow trend showing significant decline and drying in the past 10 years.



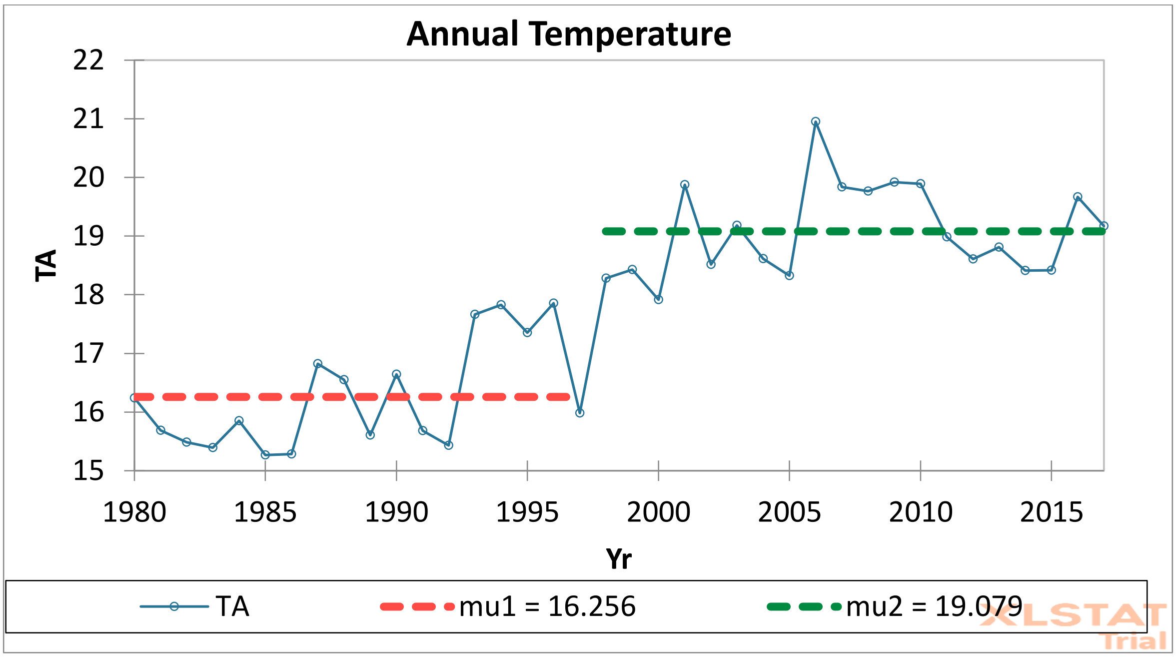


Figure 35: Pettit test indicating 1998 as year showing significant shift Maximum (a) and Annual (b) Temperature.

The association between LULC trajectory, spring flow change, and climate change over the 20-year and 10-year periods suggests a correlation between LULC trend and the spring sources drying trend (considering maximum deforestation until 2000). There is also evidence of some concurrent relation with the decreasing spring flow trend (Table 16). Furthermore, the climate change trend with a significant increase in maximum temperature and the associated change in ET and net ppt before 1998 can help justify the increased decreasing trend over time. Therefore, it suggests that change in spring flow trend is associated with the change in LULC pattern.

Table 16: Spring flow trend in past 20 years based on spring flow measurement

Change	Trend					
	20 yrs.	**10 yrs.**	**5 yrs.**	**Recent**	**Total**	**%**
No change	202				202	18
Dried up	6	1	7	12	26	2.3
Decreasing	509		291	58	858	76.5
Increasing	25	2	9		36	3.2

4.4.4 Implication of changing climate on water resources availability

These changing climatic patterns have direct implication for the agriculture-based livelihood of communities in Rangun Khola watershed. Considering the perceptions of these implications by HHs, drying water sources was the most prominent issue reported by 65% of the households, followed by impacts on plant phenology (59%), agricultural productivity (53%), water collection timing (45%), and indirect implication on the range of livelihood activities as reported by almost one-third of the households (Figure 36).

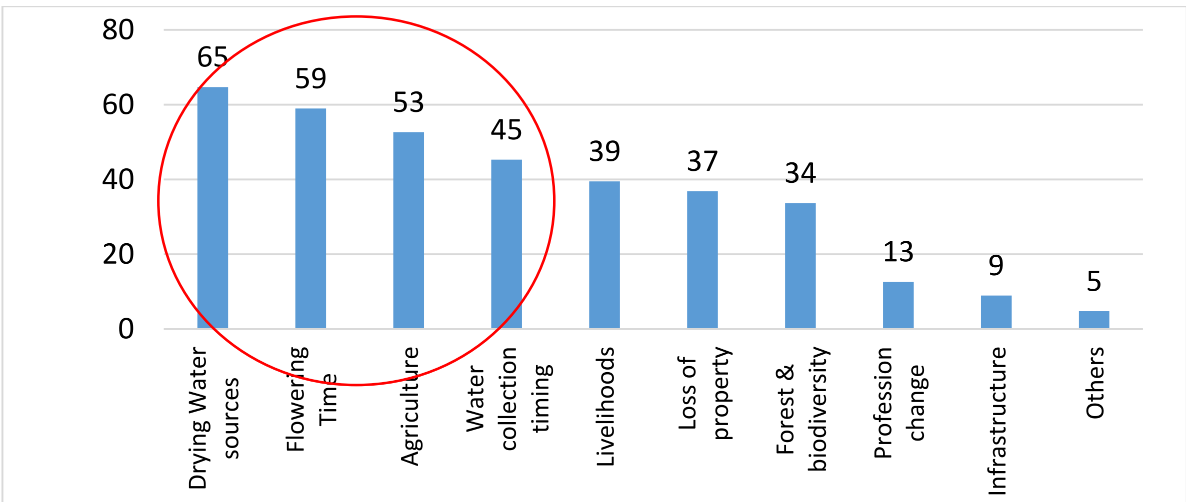


Figure 36: Sectoral impact of climate change from community lenses

At present, less than 5% of the HHs reported having access to private water sources within their HH premises, while 95% reported traveling at least 15 minutes to access the public water sources (Figure 37).

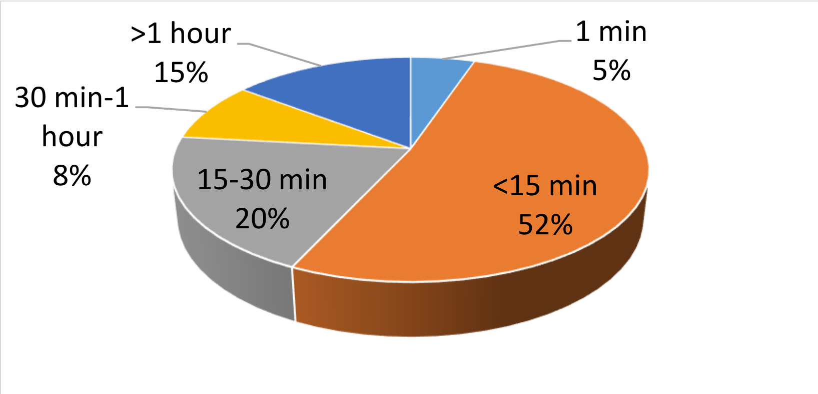


Figure 37**:** Travel time for water collection

The water management at the household level is mainly led by women (87%), while for irrigation water management it is equally shared between women (48%) and men (52%). In terms of water collection from source, 73% of HHs were practicing shared roles, while 26% of HHs reported the task as the sole responsibility of women (Figure 38).

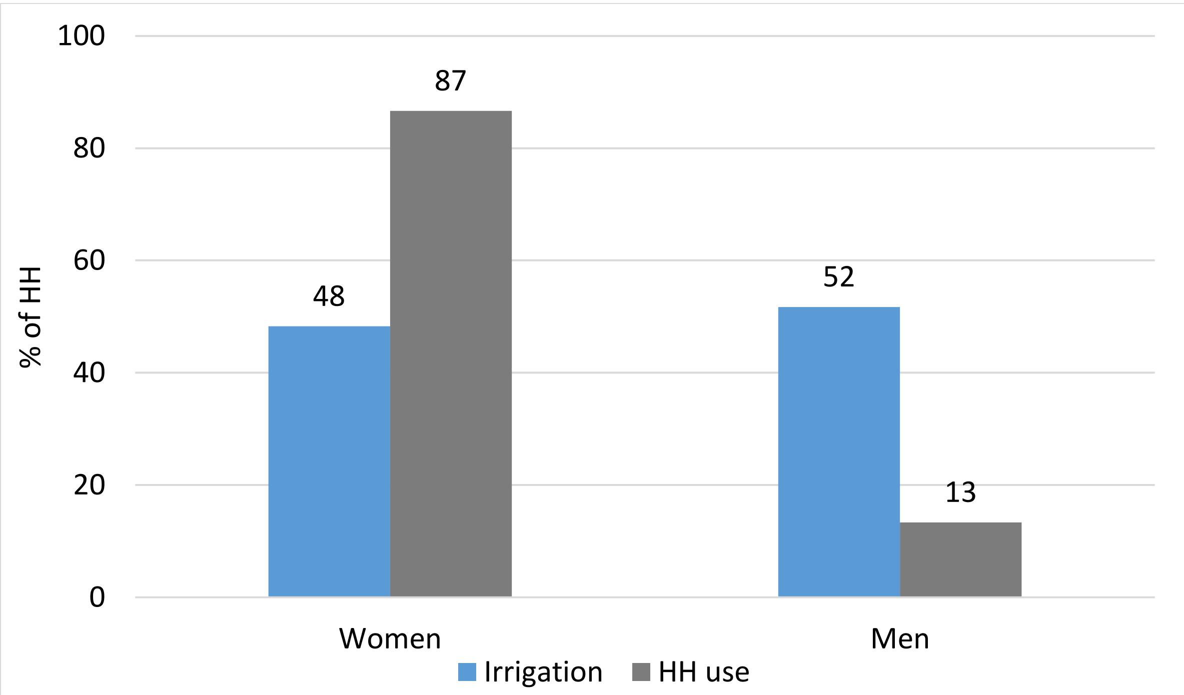


Figure 38: Water management role and responsibility in Rangun Khola Watershed

Equal access to the water source is vital for human existence. Limitations exerted by water scarcity and drying water sources was found to exacerbate pre-existing social inequity and inaccessibility to water sources. Almost 14% of the respondents reported unequal access to water resources as a result of increasing resource scarcity. Among scarcity-related hurdles, increasing water shortage in earlier reliable water sources (52%), and long-distance travel time (68%) along with associated safety issues for women as water collectors (40%) travelling to new sources, were the prominent issues identified by the community (Figure 39).

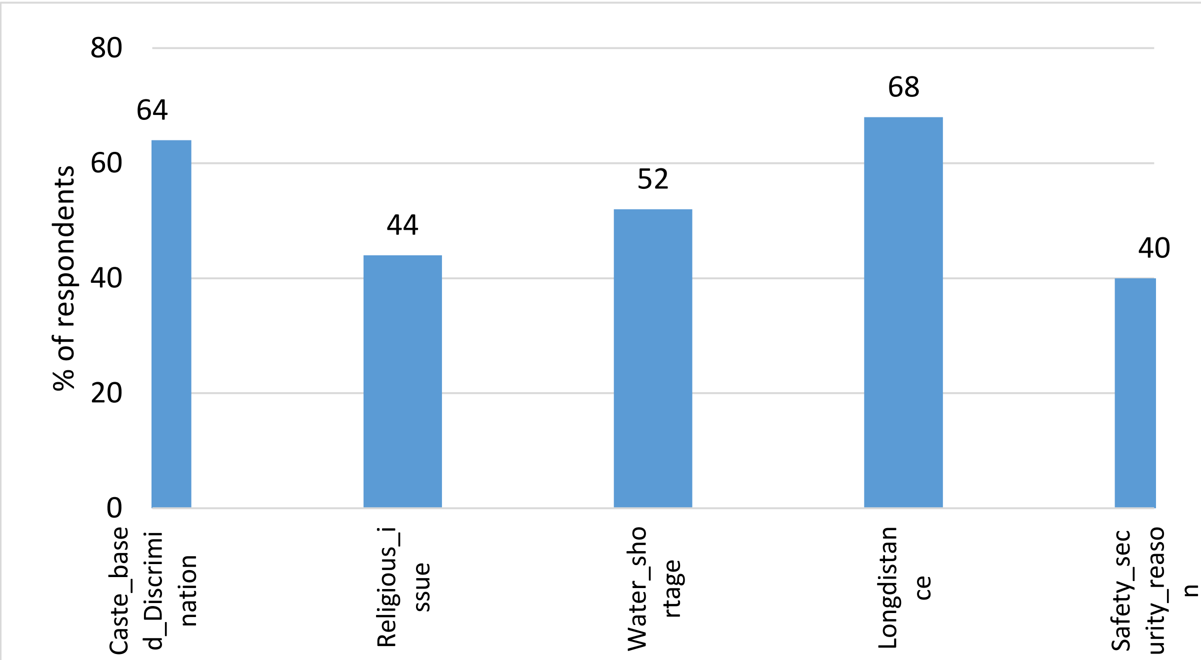


Figure 39: Causes of unequal access for drinking water accessibility

Owing to the immediate implication of drying spring sources on livelihood, almost 15% of HHs were trying out a range of risk aversion activities to reduce the immediate impact on livelihood. Among the respondents who were using risk aversion activities, almost 95% were cantered on household level interventions, such as increasing their seasonal migration activities (48%) and adjusting finances by borrowing money from local sources (41%). However, less than 5% were trying to search for an alternative water resource, such as community-level interventions (Figure 40).

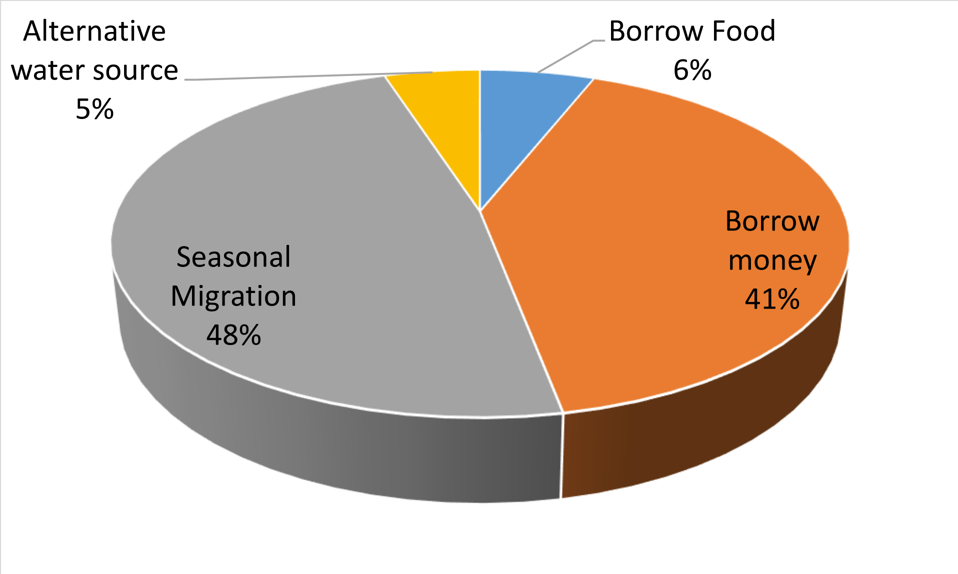


Figure 40**:** Risk aversion mechanism opted by community

Even though implications are visible at the household level, less than 25% of the HHs were undertaking coping or adaptation actions on the ground. Among the range of options, plantation was common practice reported by 23% of the household, followed by gabion wall construction (11%). Water scarcity was continually pointed to as aggravating issue, however, water source protection was adopted by less than 7% of the HHs. Protecting water sources was still lacking its place in the top two adaptation interventions against changing climate. Furthermore, there were negligible efforts to adopt adaptation measures, such as canal rehabilitation, bio embankment, and tunnel house, while alternative livelihood options were initiated by less than 2% of the households in the watershed (Figure 41).

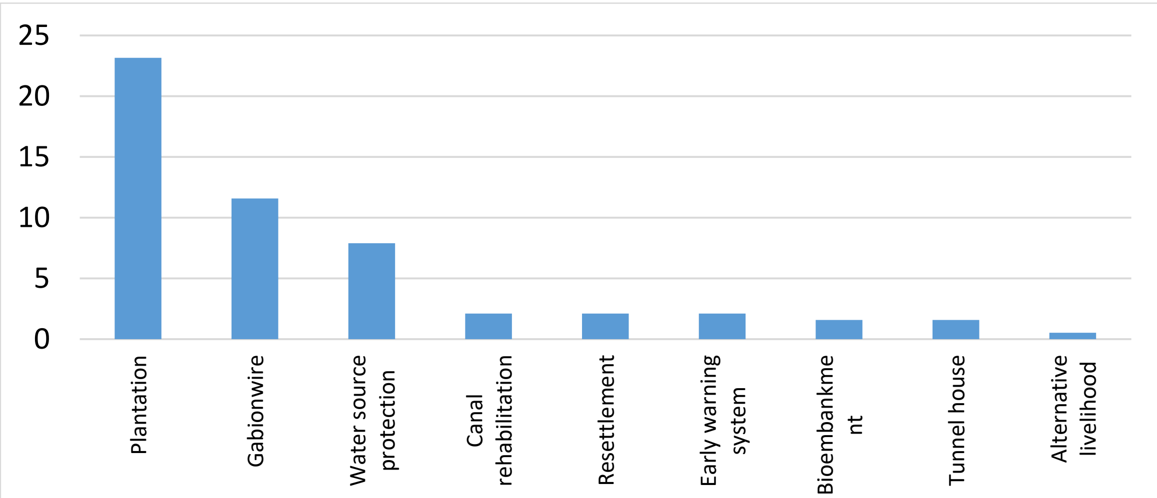


Figure 41: Community-level coping responses against climate change

4.5 Anthropogenic drivers

4.5.1 Population growth

The population density of the Rangun Khola watershed ranged from 16 persons per km to 386 persons per km, according to the CBS census of 2011 (Figure 42).

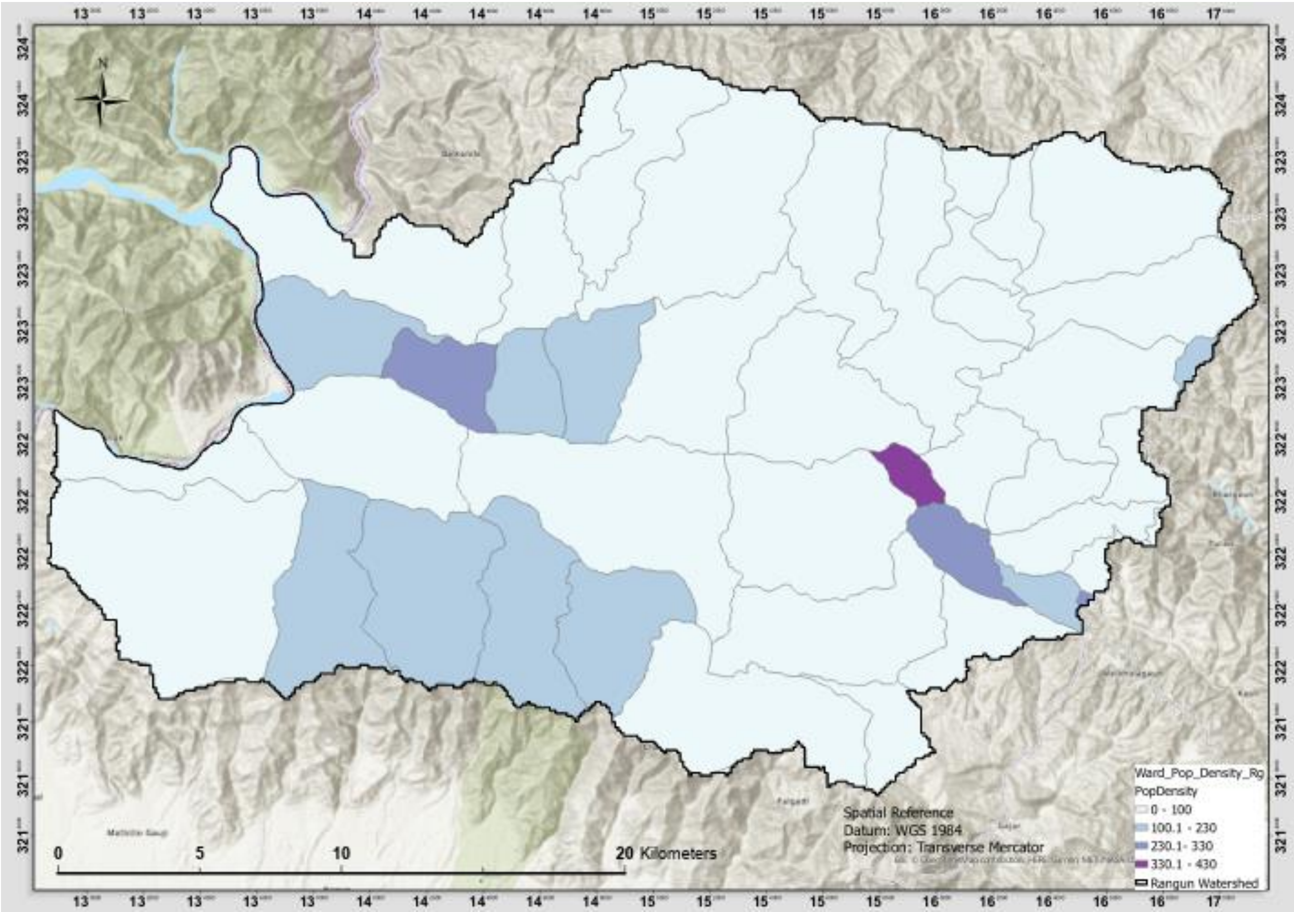


Figure 42**:** Population density distribution in Rangun Khola watershed (CBS 2011)

The population in Dadeldhura district was reported to be following an increasing trend since 1981, where 1.15 million people in 1981 increased to 1.26 million in 2001 and rose to 1.42 million in

2011(CBS 2011) By 2020, the population had increased to 1.66 million (Figure 43) .

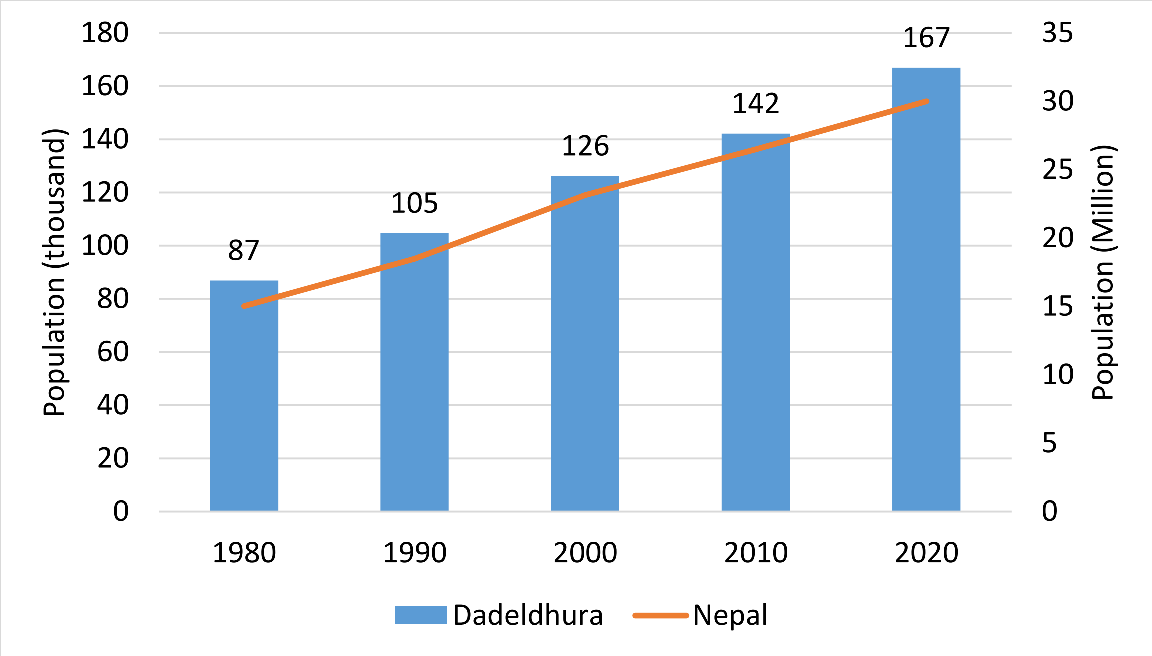


Figure 43: Population census Dadeldhura district and Nepal trend comparison (CBS 2011) (www.ceidata.com)

4.5.2 Rural road expansion

Road extension status documented in major municipalities within the Rangun Khola watershed (Alital RM and Parashuram M) revealed that more than 682 roads of different categories have been constructed within the past 10 years (Figure 44). Road development in the Rangun Khola watershed has drastically risen after a decentralized federal structure was formalized. This data available is for the roads more than 1 km length, however, much more undocumented road expansion and construction was undertaken to connect settlements to the main road. In this phase, environmental impact assessment and implementation process environmental aspects were disregarded due to time and cost constraints. For example, among 30 documented road constructions in the Alital rural municipality, environmental impact assessment was done only for 4 roads, while implementation was only done for a 6.5 km ring road.

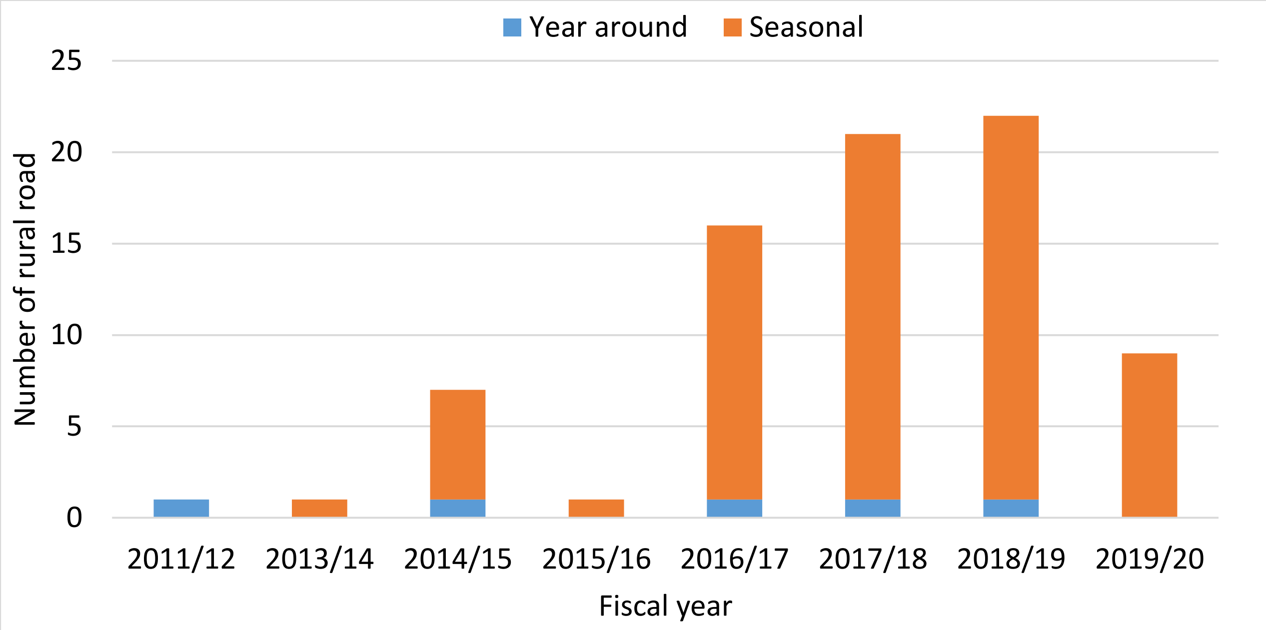


Figure 44: Annual road development in Rangun Khola watershed

The road development status comparison done for two major municipalities within the Rangun Khola watershed revealed that during 10 years almost 43 roads of various ranges accounting for 395 km rural road expansion were constructed in Parashuram municipality. Whereas, in the case of Alital rural municipality, 30 roads of 287 km were constructed in the same period. The comparative assessment revealed that rural road expansion in Parashuram municipality was almost 40% more as compared to Alital rural municipality (Table 17).

Table 17: Road development status in two major municipalities

Ward no	Alital		Parashuram	
	Number of roads	Length (km)	Number of roads	Length (km)
1	4	46.0	4	32.8
2	3	50.7	4	37.3
3	3	36.7	4	50.5
4	5	37.5	1	6.3
5	1	13.7	5	30.3
6	7	56.5	2	17.0
7	3	26.0	8	81.6
8	4	20.0	1	14.1
9			3	29.6
10			4	17.0
11			4	47.5

12			2	30.9
	30	**287**	**43**	**395**

4.5.3 Rural road extension and changing spring sources

Ward level rural road expansion and spring flow change comparison between two municipalities indicated that 312 spring sources showed a declining trend in flow with no spring sources having dried up in Alital rural municipality. In Parashuram, 471 springs have shown a declining trend with drying up of 22 springs (Table 18).

Table 18: Road development and spring source change in two major municipalities

Municipality	Spring flow		Road development	
	Decreasing flow	Drying springs	No of road	Length (km)
Alital Rural Municipality	312	0	30	287
Parashuram M	471	22	395	43

Consequently, the increasing rural road expansion in the case of Parashuram municipality was significant and correlated with an increasing number of drying spring sources (Figure 45).

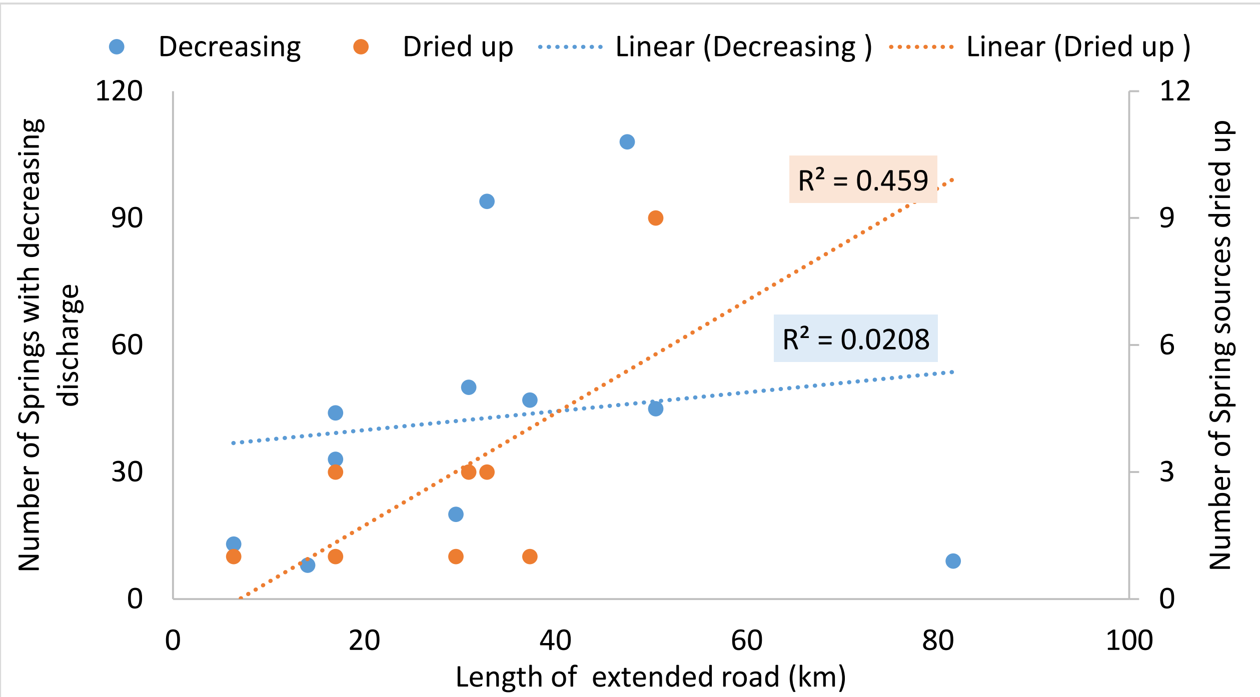


Figure 45: Road expansion and drying spring sources trend

V. DISCUSSION

Water knowledge is a product of interaction between disciplinary experts (certified or uncertified) as well as different stakeholders in the society (Krueger et al. 2016). The hydrological system is an example of interconnected biophysical and social processes, such as climate variability, water use, and infrastructure and land cover, where changes in one process imply flow-on effects in others (Vogel et al. 2015). However, these relationships have often been overlooked. Solutions to the increasing demands of the water sector and the declining availability of the water source require an interdisciplinary approach rather than approaching the problem from a science perspective only. Therefore, the objective of this research was to gain an understanding of the status, opportunities, challenges, and changing spring water resource dynamic in the physical, social, and political context of Rangun Khola watershed.

5.1 Spring water availability and trends in Rangun Watershed

5.1.1 Status of springs in Rangun Khola watershed- Inventory

A total of 1,122 spring sources documented in the study gave an overview of the status of spring water sources in the Rangun Khola watershed. With a spring density of 1.63 springs per square km, prominent springs are located in mild (0-30o) northern slope in forest and associated landforms within the elevation range of 500-1000m. Subsistence agriculture-based communities in the watershed are predominantly relying on public spring sources (95%) for their domestic and agricultural needs. Inaccessibility to supplementary irrigation support compels the communities to rely on rainfall or natural spring sources for agricultural needs, as with many mid-hills and mountain watersheds in the Himalaya (Tambe et al. 2012; Sharma et al. 2019). On average, 17 households rely on single spring sources, which illustrates the importance to communities of adequate flows from springs in the watershed. Categorizing the spring sources based on the flow rate (Meinzer 1923) showed that springs are fifth and lower magnitude with maximum discharge recorded as 3.33 l/s. Among all, 70% of springs were in the seventh and eighth class range with a flow rate below 1 l/s, whereas less than 30% were in sixth and fifth class, including 2.5% springs that were dried up. The lesser proportion in higher class springs depicted in a study done on Khar village (KC & Rijal 2017) coincided with this study. However, in terms of sixth and seventh class Khar village had a higher proportion of springs in sixth class, whereas in Rangun Khola watershed the maximum springs were in the seventh and lower classes.

5.1.2 Changing spring flow trend

The comparative assessment of flow rates between the period 20 years ago and the present revealed that nearly 76% of springs have shown a continuous declining trend in flow rate with the concurrent rise in drying up of spring sources. The declining spring flow was contributing to community perceptions where nearly 82% of households perceived reductions in water resource availability over the past 10 years. The number of springs with a flow rate of more than 0.1 l/s has reduced by 63%, while springs with discharge below 0.1 l/s have increased almost 1.5 times in 20 years. Drying up of springs has been a noticeable trend in recent years. In terms of spring orifice type, open sources are showing more abrupt changes as compared to closed sources. In the case of seasonality, even though perennial springs have declined in spring flow, seasonal spring sources have declined sharply as indicated by 10% of seasonal springs already having dried up within the last two decades. These trends are indicative of impending acute water scarcity in the Rangun Khola watershed (Rana & Gupta 2009, cited in (Mahamuni & Kulkarni 2012)).

5.2 Natural drivers of change

5.2.1 LULC change

The LULC quantification and understanding of the interaction between changing resource dynamics in any given period is a crucial component for better decision-making in water resources management (Li & Deng 2017). Gradual fragmentation of landholding is one of the emerging problems in Nepal (Paudel & Waglé 2019), and Rangun Khola is no exception with almost 50 km2 of the area undergoing land-use change. Consequently, a LULC trajectory assessment done in the Rangun Khola watershed revealed that 45.3 km2 forest transformation to agricultural land was the prominent LULC transformation over the past 28 years. A study done for the whole of Nepal indicating forest conversion to cropland (Li Ainong et al. 2017) was comparable to this study in the Rangun Khola watershed, where forest reduction and agricultural land expansion were complementing each other.

Nepal has experienced extensive deforestation as a by-product of population growth, urban expansion, and agricultural growth before 2000 (DFRS 1999 cited in (Li, Deng & Zhao 2017)). This was coinciding with the heavy deforestation, including almost 50% of recorded forest clearance, in the Rangun Khola watershed from 1990-2000. The introduction of community forestry interventions has been instrumental in stabilizing deforestation to a certain extent (Birch et al. 2014; Li & Deng

2017), which reduced the rate of forest clearance during 2000-2010. No significant association was noticed with LULC trajectory analysis (done with 30 m by 30 m LULC map) and the spring flow trend. However, a detailed assessment of the local land-use scenario around the spring sources indicated a significant association of declining spring flow with increasing disturbance in the surrounding LULC type, which suggests that undisturbed vegetation is supportive of spring protection (Negi & Joshi 2004). Forest has a higher water retention capacity than other landforms (Joshi 2006). The study by Valdia and Bartarya (1998) and Joshi (2006) was consistent with the finding that the spring location and level of disturbance in its immediate surrounding have direct implications on spring hydrology, flow dynamics, and water quality. However, for better understanding, LULC assessment with the high-resolution map was recommended for future research.

5.2.2 Local climatic variability

The increasing trend in global temperature and variability in rainfall is a common phenomenon all over the world (IPCC 2018). The climate change scenarios assessment for Nepal indicates that the average annual maximum temperature has increased by 2.4 °C (0.056 °C/y) over the 44 years from 1971 to 2014 (MoFE 2019). Ongoing global warming is resulting in global consequences (IPCC 2018) and its local manifestation in its varied forms is mostly visible as the impact on water resources (Nistor 2016). Communities in the mountain are perceiving the changes in climatic pattern, precipitation variability, and increase in extreme events (Karki et al. 2017). In addition to learning about changing climate from scientific sources, communities in the Rangun Khola watershed have observed evidence of the local climatic variation directly in the form of increasing temperature, declining precipitation, increasing natural disasters, and increasing water scarcity.

Local climate data assessment done at the closest Dadeldhura weather station revealed that community perceptions of local manifestation of climatic parameters are close to reality. The significantly decreasing number of days with precipitation more than or equal to 1 mm with concurrently increasing high-intensity rainfall (R99p) is indicating towards the increasing frequency of localized high-intensity rainfall events (Talchabhadel et al. 2018). This alteration in magnitude and frequencies of precipitation patterns in association with significantly inclining temperature trend is indicating the associated risk of extended dry periods in the adjoining localities (Bastakoti et al. 2017; Karki et al. 2017). Precipitation, one of the most important parameters of the hydrological cycle, is directly affected by global warming. As a result, natural spring flow that receives input from rainfall as precipitation infiltrating the ground is also affected (Agarwal et al. 2012).

Furthermore, the local value of the climate change scenario has higher variability than the regional setting. Warmer temperatures, prolonged monsoon, and sporadic rain events are common across the region. The data of the Dadeldhura station shows similarity with the regional trend, RCP 4.5 projection T max- (1—4.5 0C), present rate is 0.05 0 C, precipitation (-7.05-20.7%) (Dhaubanjar, Pandey & Bharati 2020). These changes are expected to distress almost every sector with severe implications on water demand and availability (MoPE 2017). Microclimatic variation implies the direct implication on the spring hydrograph (Agarwal et al. 2012). The accumulated impact of increasing global temperature and altered local rainfall regime, contributing to variation in the amount of effective infiltration with direct implication on spring discharge (Fiorillo, 2009), was evident in the springs in the Rangun Khola watershed. The changing local climate has greater implications on seasonal springs (Negi & Joshi 2004). However, the present level of visible changes in the spring flow pattern, 1% of perennial spring already having dried up in Rangun Khola watershed, underlined the severity of the water scarcity scenario (Valdiya & Bartarya 1991). The local climate variability concurrent with drying spring sources appears to validate the community perception of decreasing water availability as a combined impact of changing climate (Lamsal, Kumar & Atreya 2017; Pandit et al. 2016).

5.3 Anthropogenic drivers of change

The population growth of Dadeldhura, which almost doubled in 40 years (CBS 2011), followed by flourishing urban development (Portnov, Adhikari & Schwartz 2007), is one of the major anthropogenic pressures on the available water resources. Even though no significant direct relation was observed between population density and changing spring flow, the associated implication of urban growth on spring sources should not be discounted. For example, a significant increment in the number of drying spring sources occurred concurrently with the expanding road network in Parashuram municipality, which revealed that drying spring sources may be associated with road expansion.

Under the new Constitution 2015, Nepal has adopted a three-tier structure of federalism, which are federal, provincial (7), and local (753) bodies further divided into 6740 wards as the lowest units of the government. After the 2017 election, federalism came into operation (Babu & Sah 2019). The federal political system decentralized the responsibility and power to the local level along with ownership of public investments (Paudel & Waglé 2019). The unlocked opportunity was seized by local leaders, who were equipped with power and under pressure to satisfy the local need in infrastructure development, especially in the road sector (e.g., track opening, road expansion, and new construction). The road extension resulted in 682 documented road expansions in the Rangun Khola watershed. Geologically, the Rangun Khola watershed lying in the lesser Himalaya, is characterized by highly fractured rocks, peculiar with underground fault line presence in the region (Dhital 2015), which increases the vulnerability to abrupt changes.

Past researches have shown that the hydrogeological alteration resulting from vegetation change has a higher possibility of recovery than hill slope hydrology resulting from road construction (Jones & Grant 1996; La Marche & Lettenmaier 2001). The haphazard road construction in the hill slope as a combined effect of obstructed infiltration and aggravated surface flow triggers soil erosion which ultimately alters the hydrogeological processes and ecosystem functioning in the watershed (Saraswati et al. 2020). The triggered extensive haphazard road construction in the watershed has thus led to greater implications on natural resources especially visible in the water sector in the form of drying springs in hill slopes.

5.4 Implication of the drivers on spring resources in mountain

5.4.1 Ecosystem and livelihood implication

The mountain ecosystem has higher sensitivity to LULC and climate change. Accelerated LULC change, meticulously allied with the human development pathway, has sectorial impacts on land water resources leading to subsequent implications on ecosystem services delivery (Li & Deng 2017). Extensive deforestation in the past along with agricultural land expansion cumulating with local and global change factors (e.g., population, urbanization, development intervention, climate change) (Li Ainong et al. 2017) has resulted in exaggerated impacts on ecosystem services especially water resources (Li & Deng 2017). The effect of decreasing water availability from natural causes is exacerbated by increasing demand from anthropogenic pressure on the limited water sources in the Rangun Khola watershed.

The increasing water shortages in the watershed, observable as decreased spring discharge and drying spring sources, resembles many studies done in other parts of the Himalayan region (Tambe et al. 2012Sharma et al. 2016;Poudel & Duex 2017). The drying sources and degrading spring flow have adversely impacted the quality, quantity, and timing of water availability, affecting local lives and livelihoods (MoPE 2017). In terms of spring discharge change trend, irrespective of size, discharge reduction is a common phenomenon in the western Himalaya (KC & Rijal 2017). However, the pronounced impact was more visible in smaller sources. Unlike the extensive spring restoration activities followed by action research taking place in western Himalaya (Tambe et al. 2012; Sharma et al. 2019), communities in the Rangun Khola watershed are limiting activities to short-term risk aversion interventions. Larger dependency of the majority population on the declining spring sources (Mahamuni & Kulkarni 2012) in combination with limited short-term coping mechanisms and risk aversion interventions suggests a higher vulnerability associated with climate change implication in the Rangun Khola watershed.

5.4.2 Social Implication

Almost 43% of HHs in the Rangun Khola watershed are investing more than 15 minutes, while almost 15% were investing 15 minutes just for water collection. Increases in water collection time was among the top climate change implications reported by the households in the Rangun Khola watershed. The drying water sources or shifting watercourse is expected to be a serious concern for such households, which are already investing more time to fetch water (Chapagain & Gentle 2015). Women are the lead in household water management in the mountain communities (WECS 2011) concomitantly in the Rangun Khola watershed, women are responsible for domestic water management in 87% HHs and agricultural water management in 48% HHs. In the case of droughts and reduced water availability, women as primary water managers need to spend a considerable amount of time collecting drinking water, so they are certain to be directly affected. (MoPE 2017). The altered water collection time is expected to add to their existing workload and lead to greater implications on gender roles and economic productivity (Udas et al. 2019). In addition to the direct impact on health and wellbeing on women and girls, threats to their safety, decreasing productivity in other areas like farming, and reducing the time available for schooling and other productive activities are the associated gendered implications of climate change on society (Chapagain & Gentle 2015; Macchi, Gurung & Hoermann 2015).

The drying up of springs in the mountainous region is one of the reasons for community displacement in some areas of the country (Chapagain & Gentle 2015), which is adversely affecting the economy of the region (Agarwal et al. 2012). At present, seasonal outmigration is one of the secondary livelihood options people are relying on for survival. However, researchers have exposed that the drying up of springs in the mountain is one of the growing causes of outmigration from mountain communities to areas with more water availability (Chapagain & Gentle 2015). The continued spring source depletion without any intervention in restoration activities in the Rangun Khola watershed has a high possibility of further adverse impact on livelihood and ecosystem over time.

5.5 Policy Gap

The Niti Aayog, 2018 of India, documented the restoration of springs in the mountain region as one of the priority areas, which brought some positive messages to the HKH member countries (NITI 2018). In the case of Nepal, in the process of restructuring institutional arrangement and policy harmonization, water resource management comes under all three government structures and many plans and policies are still in process of finalization (Nepal et al. 2021). There are some policies, such as Drinking Water Rules, and the Water Resources Act 1992, which are acting as umbrella policies covering the areas of water supply and consumers licensing. However, specific initiatives for protection of spring water sources, their restoration and revival are missing. The government of Nepal has taken few initiatives in the sector of integrated water resource management. Watershed management is considered one of the important components of the municipal environment Protection and Natural Resource Management Act 2077. Climate Change Policy, 2019, has highlighted the importance of recharge ponds for recharging groundwater. Likewise, in the budget of the fiscal year 2019/20, the plans for construction of 200 ponds in Siwalik and Mahabharat region to recharge groundwater, was mentioned under President Chure Conservation Program. Similarly, a few of the local governments have also initiated a spring restoration program in some localized areas.

However, there are numerous gaps in terms of prioritization of the spring source management aspects and their contribution to the local economy and environmental services, and in the federal plans and policies. The local act mentioned water source identification, documentation, conservation, and management under the jurisdiction of Rural Municipality. Environment and NRM conservation council in the leadership of rural municipality, municipality chief with several committees under this council are considered responsible for monitoring and evaluation of development activities within municipalities. However, when it comes to implementation, the environment monitoring and evaluation officer posts are empty at a municipal level within the

Rangun Khola watershed and it was found that the environment impact assessment was not taken seriously. As in the case of Alital rural municipality, among the 30 major road projects developed only 1 for 6.5 km ring road had implemented environmental impact assessment. The lack of effective implementation due to the incapability of local institutions on contemporarily emerging issues is one of the pitfalls among many (Regmi & Shrestha 2018). Furthermore, there is a significant gap in the institutional levels for ensuring the funding allocation for action research and sustainable development activities (Joshi & Joshi 2019), which is one of the greatest hindrances for spring resources management in the Himalayas.

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 Research outcome

Spring resource assessment in the Rangun Khola Watershed revealed that alike many mountain watersheds, springs are the primary source of water in the study area. Springs in Rangun Khola watershed ranged from fifth class (<10 l/s) to eighth class (<0.01 l/s) range with prominent (73%) one falling below seventh class (<0.01 l/s). The reduction in flow trend was also verified by the significant reduction in the number of springs with flow rate >1 l/s from 43 to 12 within 20 years and consequent increment in several dried springs from 0 to 26 and spring with low flow rate <0.01 l/s from 381 to 581. This change in the spring flow trend was further supported by the household questionnaire survey conducted in the watershed. The household questionnaire survey and interaction with local stakeholders revealed that due to declining natural spring flows and drying water sources, increase in water collection time was one of the major consequences faced by the households in the Rangun Khola watershed.

The LULC change and local climatic change pattern assessed for the Rangun Khola watershed revealed that LULC change along with changing global and local climatic patterns are the natural drivers of change for spring resources in the mountain. In addition to these ongoing natural drivers, population growth and development intervention, and haphazard rural road construction is overburdening the natural drivers and contributing to the changing dynamic of spring flow in the mountain. The accumulated impact of these drivers is leading to drying spring sources. This changing phenomenon and its implication on local livelihood are perceived by the community which has begun facing the consequences of water scarcity. However, neither government nor local households are undertaking adequate mitigation and adaptation intervention in the watershed to overcome the problems of water insecurity. Despite facing water scarcity, households and communities are not taking concrete actions on resource protection. The government, which should be actively engaged with the community on environmental issues through the water resource protection and conservation agencies and activities, has not prioritized the importance of strategies to mitigate impacts of climate change and human development in an environmentally responsible way.

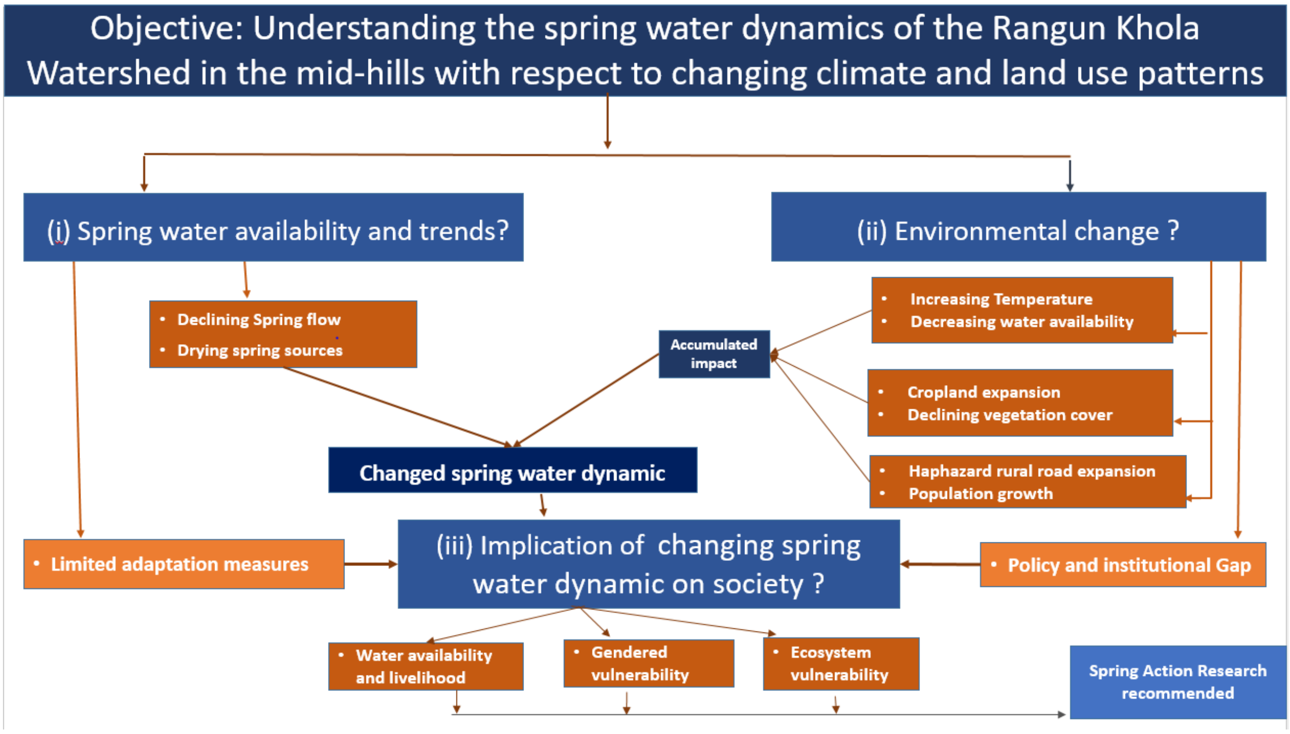


Figure 46: Research objectives and outcome

This continued negligence in spring resource management following the business-as-usual scenario is indicating the likelihood of critical long-term implications on the ecosystem and the local economy in Rangun Khola and similar watersheds in Himalaya. Referring to other studies in the mountain zones, the implication which begins with water scarcity, increased workloads for women, impact on local biodiversity, and reduction in agricultural productivity is expected to result in longer term social conflict, decreased overall social performance, and community displacement.

6.2 Study limitations

The limitations of this study are that it is was primarily based on a single spring source mapping study and HH perception assessment done during 2018. The land cover change assessment was based on a 30 m by 30 m resolution map prepared by ICIMOD, while the indicative climate change assessment was based on the nearest Dadeldhura weather station due to incomplete data availability from other stations.

6.3 Recommendation for future research

This research has presented a study of the social hydrological status and documentation of drying spring sources in the Rangun Khola watershed and has developed the following recommendations:

- This is merely the first level indication of changing spring sources in the mountain; however, continuous monitoring of status and flow trend is prescribed for proper water resource management in the mountain.
- Observing the aggravating problem of drying springs in the last decade, the dire need to develop and mainstream the watershed management plan focusing on spring water sources at local developmental government planning is recommended.
- Detailed assessment of status and the underlying cause of changes for spring sources in mountains need to be conducted in other watersheds in the mountain region along with timely action on the ground for sustainable management of spring sources in the watershed.
- The timely research and successful piloting can lead to a way forward for similar watersheds in the region and associated mitigation measures investigation is recommended.
- Most important of all, the research findings and recommendations need to be communicated in understandable language to the concerned stakeholders within the watershed to make the best use of this research.

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APPENDICES

Appendix A: Household survey questionnaire

Questions	Options
Respondents Detail	
Name of watershed	
District	
Municipality	
Ward No.	
Village/ Clusture	
What is your name?	
Gender	Male Female Other
Age	
Respondent's caste/ethnicity	Hill Brahmin/Chetri/Thakuri/Sanyashi
	Hill Dalit
	Terai Dalit
	Indigenous nationalities
	Madheshi Brahmin/Chetri
	Other Madheshi caste
	Religious minorities

	Livelihood and Wellbeing		
	Question	**Option**	**Coding**
1	What is the primary livelihood activity for your family? (single choice)	Capture fisheries	
		Fish farming	1
		Capture aquatic invertebrates/vertebrates	**3**
		Livestock	**4**
		Poultry	**5**
		On farm (crops, vegetables, fruits)	**6**
		Dairy	**7**
		Off farm (handicraft, grocery, tea shop, small business, trade)	**8**
		Traditional occupation (blacksmithing, tailoring, shoe making, carpentry , faith healers, priest, *gainer* etc)	**9**
		Hospitality (hotels, lodge)	**10**
		Daily wages (mining, sand, grave, road construction)	**11**
		Seasonal migrant	**12**
		Job in Nepal	**13**
		Job abroad	**14**
		Pension/social allowance	15
2	What is your alternative/secondary livelihood activities? (multiple response question)	Capture fisheries	
		fish farming	
		Capture aquatic invertebrates/vertebrates	
		Livestock	
		Poultry	
		On farm (crops, vegetables, fruits)	
		Dairy	
		Off farm (handicraft, grocery, tea shop)	
		Traditional occupation (blacksmithing, tailoring, shoe making, carpentry etc)	
		Hospitality (hotels, lodge)	
		Daily wages (mining, sand, grave, road construction)	
		Seasonal migrant	
		Job (Nepal and abroad)	
		Job abroad	
		Pension/social allowance	

Q. No	Questions	Options	Skips
		DRYING WATER SOURCES	
1	What is the primary source of your drinking water? (Single answer question)	Piped water (at home/community/) Can you tell me what is the source of the piped water (single answer question) River Stream Canal Pond Lake Spring Stone tap Ground water (e.g. boring)	1
		Well (with cover/without cover)	2
		tubewell_boring	3
		Waterfall (safe/unsafe)	4
		River	5
		Stream	6
		Canal	7
		Pond	8
		Lake	9
		Spring	10
		Stone tap	11
		Rain water	12
		Bottled water	13
2	Is this a private or a public source?	Private	
		Public	
3	In your family who primarily fetches water?	Men	
		Women	
		Boy child	
		Girl child	
4	How long does it take to bring drinking water?	Available at home	
		Below 15 minutes	<15 min
		15 - 30 minutes	15-30 min
		More than 30 minutes to 1 hour	30 min-1 hour
		More than 1 hour	>1 hour
5	Do you have access to use the available water resources equally as other members of the communities?	Yes	Q7
		No	
6	What are the barriers that prevent you in accessing public water sources?	Caste based discrimination	
		Religious issues	
		Shortage of water	

		Safety and security issues	
		Time consuming/long distance	
7	In your opinion, has the water sources dried than before or is same as before or has increased than before ?	Dried/Decreased	
		Same	Q12
		Increased	
8	Have you come across any difficulties due to drying of water sources?	Yes	
		No	Q12
9	What kind of difficulties have you come across? (multiple answer question)	Livelihood	
		Domestic (cooking, cleaning etc.)	
		Irrigation	
		Reduce in Hydropower supply	
		Livestock	
10	Are you practicing any ways to overcome these difficulties?	Yes	
		No	Q12
11	If yes, can you share what you are doing to overcome these difficulties?	Migrate seasonally to make money	
		Borrow food and grains	
		Borrow money from lenders	
		Others___________	
12	Which water source do you use to irrigate your land primarily? If yes, can you share what you are doing to overcome these difficulties?	Canal from river	
		Canal from lakes/ponds	
		Ground water (boring, hand pump, well)	
		Pond	
		Solar lifting	
		Collection tank/jar	
		Lake	
		Rain water harvesting	
		No land	
		Others___________	
13	Is this irrigation system permanent or seasonal?	Permanent	
		Seasonal	
14	Is the water sufficient to irrigate your land throughout the year?	Sufficient	
		Not sufficient	
15	In your family who primarily makes decisions on activities related to use and control of available water resources for household use?	Male	
		Female	
	In your family who primarily makes decisions on activities related to use and control of available water resources for agricultural need?	Male	
		Female	

Q No	Questions	Options	Skips
CLIMATE CHANGE PERCEPTION AND RESPONSES			
1	Have you hear about climate change?	Yes	
		No	Q 3
2	From where you heard about climate change?	Newspaper	
		Trainings, Workshops	
		Radio, TV	
		Schools and college	
		Friends	
		Self	
		Others	
3	**Now, I am going to read some statements about the effects of climate change. Please let me know your experiences.**		
3a	Compared to the past 5 or 10 years, has the heat increased or decreased or there is no change?	Increased Decreased No change Don't know	
3b	Compared to the past 5 or 10 years, has the amount or rain increased, or decreased or there is no change?	Increased Decreased No change Don't know	
3c	Compared to the past 5 or 10 years, has the duration of dry season increased, or decreased or there is no change?	Increased Decreased No change Don't know	
3d	Compared to the past 5 or 10 years, has the amount of water in the water sources increased, or decreased or there is no change?	Increased Decreased No change Don't know	
3f	In the recent years have you seen any plants which are new or never seen before around you?	Yes No	
3g	Do landslides occur in your community/village?	Yes	
		No	3i
3h	Compared to the past 5 or 10 years has the landslides increased, or decreased or is as usual?	Increased Decreased As usual Don't know	
3i	Compared to the past 5 or 10 years has the agricultural production increased, or decreased or there is no change?	Increased Decreased No change Don't know	
3j	In the past 5 or 10 years has the number of native fish increased or decreased or there is no change?	Increased Decreased	

		No change Don't know	
3k	In the past 5 or 10 years has the number of exotic fish increased, or decreased or there is no change?	Increased Decreased No change Don't know	
3.2	In which areas have you or your family felt the effects of climate change?	Human Health	
		Water sources (drying of water sources)	
		Forest resources and biodiversity	
		Agriculture	
		Change in the flowering season of fruits	
		Occupation/business	
		Physical infrastructure	
		Decrease in Livelihood	
		More time to fetch water	
		Loss of property and human lives	
		Others	
4	Are you doing anything to overcome these challenges?	Yes	
		No	Q6
5	Can you tell us what are you doing to overcome these challenges? (Multiple answer question)	Use of gabion wire	
		Plantation	
		Resettlement to safer place	
		Source protection	
		Follow early warning system	
		Plastic pond, cement or stone masonry tanks	
		Drip and sprinkles irrigation	
		Adopt alternative means for livelihood	
		Bio embankment	
		Improved/hybrid seeds	
		Use of plastic house or tunnel for vegetable production	
		Shallow tube well	
		Canal construction, rehabilitation	
		Solar lift irrigation	
		Use of drought and flood tolerance seed varieties	
		Others	

6	Why you have not done anything? (Please do not ask to those who responded 'yes' to Q4)	Not enough knowledge to try it	
		Not enough labour available in the household	
		Lack of technical supports	
		Too expensive	
		Too complicated	
		No one is using in our village	
		Not worth the effort	
		Others	
7	Are you involved in agricultural works?	Yes	
		No	Q 15
8	Compared to the past 5 or 10 years has the soil fertility increased or decreased or there is no change?	Increased	
		Decreased	Q10
		No change	Q 11
9	What are the reasons for the increase in soil fertility? (Only ask for those who have responded 'increase' in Q 8	Use of organic fertilizer	
		Use of biological fertilizer	
		No use of chemical fertilizers	
		Improved seeds	
		Rotational cropping	
		Improved irrigation	
		Adequate and timely extension services	
		Others	
10	What are the reasons for the decrease in soil fertility?	Decrease in population of earth worms, frogs	
		Excessive use of chemical fertilizer	
		Decrease in use of organic/compost manure	
		Loss of top/nutrient rich soil	
		Others	
11	Which type of fertilizer do you use in the field?	Biological	
		Chemical	
		Organic	
12	Are you experiencing a lot of problems with pest in crops, or a little problem or not at all?	Little problem A lot of problem No problem at all	
13	Have you heard about Integrated Pest Management?	Yes	
		No	Q15
14	Have you used it?	Yes	
		No	
15	Is there a disaster risk reduction committee in your community?	Yes	
		No	Q18
16		Yes	

	Are you affiliated with this committee?	No	Q18
17	In what role you are affiliated with?	Chairperson / Vice Chairperson	
		Secretary/General Secretary	
		Treasurer	
		Advisor	
		Member	
18	Do you think you have equal access to the information on disaster risk reduction?	Yes	Q 20
		No	
19	What are the barriers for you not to have equal access to disaster risk reduction related information?	Not aware on the available services/information Never asked for the available services/information Social discrimination (e.g. cast, ethnicity, gender, illiteracy etc.)	
20	Do you have an early warning system on disaster risk ?	Yes	
		No	End interview
		Don't know	End interview
21	Do you think you have equal access to the early warning system like other members in the community?	Yes	End interview
		No	
22	What are the barriers for you not to have equal access to the early warning system?	The system is installed away from house / lack of access to the technology (e.g. mobile phones, SMS etc.)	
		Poor management of the committee/s related to EWS	
		Inactive EWS	
		No information on time	
		Hesitant to use the system	
		Social discrimination (e.g. cast, ethnicity, gender, illiteracy etc.)	

Appendix B: Spring Source Mapping checklist

Spring Source Mapping	Response
Spring ID	
District	
Municipality	
Ward number	
Place name	
Spring Name	
Spring Type	
Slope	
Aspect	
Spring Type	
Trend of spring discharge	
How much time did it take to fill the Jar of 20 liter before 20 yr?	
How much time did it take to fill the Jar of 20 liter before 10 yr?	
How much time did it take to fill the Jar of 20 liter before 5 yr?	
Surrounding Environment	
Purpose of Use	
Estimated number of households benefited	
Approx. distance from the nearest household (m)	
Method of flow rate measurement	
For flotation method- Distance taken in cm	
For flotation method- average depth measured in cm	
For flotation method- average width measured in cm	
For flotation method- time taken to float OR for bucket method- time taken in seconds to fill bucket of 5 litre OR For Perception based method, time taken to fill the bucket of 20 litre?	
Volume of bucket/jar	
Flow rate/velocity	
Flow rate (L/sec)	
Take Photo	
GPS locations (Latitude)	
GPS locations (Longitude)	
GPS locations (Altitude	
GPS locations (Precision)	