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Recent Trends in the Study of Springs in Nepal: A Review

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ABSTRACT

Springs, a component of groundwater systems, are a vital source of fresh water for fulfilling people's demand for drinking water, household uses, and irrigation, especially in the Middle Hill region of Nepal. Springs provide water for base flows and lifelines for many rivers originating from the Middle Hill regions. The present study reviews a recent trend of spring studies and investigations in Nepal through a systematic search of published and unpublished works related to springs, which are freely available. The results show 47 publications, out of 30 are published, and 17 are unpublished. The origin of published work is mainly related to project-related works, whereas unpublished works come from the academic sector for fulfilling academic criteria for thesis research. According to the physiographical division of Nepal, the study area falls in the Middle Hills of Nepal, with the maximum area located in Bagmati Province. Most of the studies that qualitative rather than quantitative information of springs. Studies are not linked with spring source and their seasonal dynamics. However, clearly available data, attributes and information about springs from 47 reviewed documents are noted. Systematic data generation and a standard framework for data collection are also missing. Nevertheless, out of 47 studies, including 11 published and 4 unpublished, the total number of springs per sq. km. in the Middle Hill region of Nepal is estimated as 2.57, which can be integrated after more research on future springs–related work.

Keywords: Groundwater, Nepal Himalaya, Spring water quality, Water resources

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INTRODUCTION

Spring represents a groundwater component of hydrological systems, which appears as freely flowing groundwater at the earth's surface. Springs are vital natural resources crucial in sustaining ecosystems and meeting communities' water needs worldwide. A spring is an out flow groundwater, i.e. an aquifer or into a body of water, such as a stream, lake, or sea. It happens when water from underground sources reaches the Earth’s surface or the water level of a nearby water body (Britannica, 2020). In Nepal, where most of the land is covered with hills and mountains, springs are vital drinking water sources for households, agriculture, and hydropower generation (Nepal et al., 2021; Ghimire et al., 2019; Gurung et al., 2019). The hydrology of springs involves investigating the sources of groundwater that feed the springs, the factors influencing their flow patterns, and the mechanisms that control their discharge.

Although, an overall recognition of springs' distribution and seasonal dynamics with natural processes and anthropogenic activities is less understood. A significant study of springs in Nepal, which aims for an inventory of springs with a primary focus on gathering qualitative and quantitative parameters, is at the initial stage now. Such studies are dispersed in terms of types of parameters because studies are either project-based or academic-based. Therefore, this study attempts to determine the current stage of spring studies and works concerning springs in Nepal. The study includes reviewing published and unpublished freely available academic thesis reports and published works on web sources.

METHODOLOGY

A comprehensive search was conducted in the study to find published (PS) and unpublished (UPS) studies relevant to the study of spring water in Nepal. The selection criteria are defined for searching documents (Figure 1). A total freely available 30 PS and 17 UPS in national and international journals were included in this review.

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Among them, 41 include typical studies related to springs and generating primary data in different areas of Nepal. The springs studies used to prepare this article are listed in Annex 1 and 2.

At first, Research4Life, Google Scholar, and Google were used to search for literature. Using two groups of keywords—one identifying GROUNDWATER or MOUNTAIN AQUIFER and the other characterizing the location of NEPAL—in the title, abstract, or keywords of the publications, the advanced search method was applied for Research4Life. The same set of keywords was also utilized to find additional papers that were contributed to the Mendeley literature database using Google Scholar and the Google search engine. A separate search was conducted for WATER QUALITY and GROUNDWATER SPRING, yielding a total of 2190 literature records initially, of which 1000 papers remained when surface water was eliminated.

First, the papers were reviewed using the title, abstract, and keyword filters to ensure they met the review's goals. Excluded from consideration were studies on Middle hill springs in Nepal that did not address surface water, groundwater in plain regions, or groundwater wells. As a result, just 30 articles of literature were left allowed for the final screening, and those were downloaded. The literature containing information about spring water in Nepal was identified through skim reading and added for review. A total of thirty full text online publications were found as a result, ready for a thorough review.

The studies were first grouped according to the variable of interests, which included the title, authors, affiliations, publication year, subject focus, and locations. After that, the final sorted documents were reviewed, and data was extracted from the literature regarding geographical distribution to create the checklist of springs. For the spring water study, bibliometric and study area-specific analyses were performed to achieve the predetermined research goals.

RESULTS

Status of spring-related studies

Out of 30 published articles and 17 unpublished but approved for academic degrees related to springs, the publication of PS shows the progression of research advancements over three years, namely 2019, 2020, and 2021. Moreover, the number of UPS peaked in 2021, showing a significant increase in research activity and data collection (Figure 2).

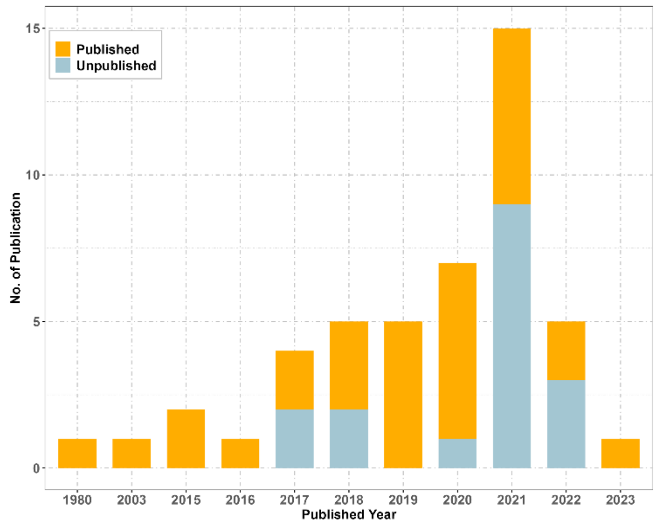

Fig. 2: Stack diagram of published and unpublished articles of springs study in Nepal.

The PS articles were sourced from various national and international agencies. Five articles were published by the International Centre for Integrated Mountain Development as working papers (Sharma et al., 2016), a manual, and a management plan (ICIMOD, 2021). As an imperative policy document, a PS was included from the National Water Conservation Foundation (Dahal et al., 2021). Six articles were included from national journals such as Banko Jankari, Bulletin of the Department of Geology, Journal of Nepal Geological Society, Journal of Institute of Science and Technology, and

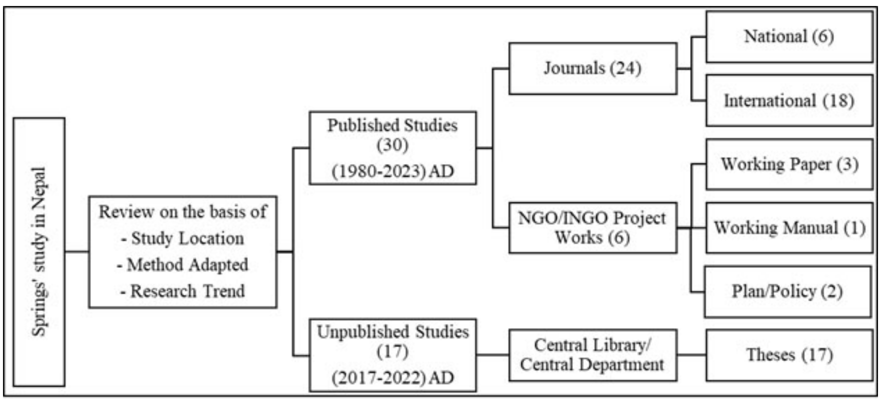

Fig. 1: Flowchart of springs study in Nepal.

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Out of thirty published articles, a total of 18 PS were published in international journals such as Tectonophysics, Mountain Research and Development, Groundwater of South Asia, Environment, Development and Sustainability, Journal of Geoscience and Environment Protection, Science of The Total Environment, Journal of Earth System Science, Hydrogeology Journal, Environmental Earth Sciences, Journal of Geographical Research, Water Practice and Technology, Environmental Earth Sciences, Journal of Hydrology: Regional Studies, Environmental Challenges, Research Square, and Mountain Research and Development.

Study area and data collection approach

A total of 47 (PS and UPS) spring related documents and articles were sampled to assess spring studies in different provinces of Nepal. Among the provinces, Koshi stands out with 3 PS and 4 UPS, showing a significant research focus on springs in the region. Bagmati Province displays many studies, with 12 PS and 7 US, showcasing a robust exploration of springs in the region. Similarly, Gandaki Province has 4 PS and 2 US, suggesting moderate research activity. Lumbini Province reveals a moderate research interest with 6 PS and 2 US. Karnali Province has fewer studies, with 2 PS and 2 US, indicating a lower level of research attention. Lastly, Sudurpaschim Province demonstrates a strong research inclination, boasting 12 PS. The spring studies highlighted variations in research activity on springs across the provinces of Nepal, directing potential disparities in knowledge and understanding of this vital natural resource.

Nepal shows a wide range of altitudes, from 64 m at Kechana in the southeastern plains to the towering height of 8,848.86 m at the world's highest peak Mount Everest. Remarkably, these extreme altitudes are found within a relatively short aerial distance of approximately 150 km, resulting in rapid changes in climate from subtropical conditions to arctic environments (Dhital, 2015), as shown in a physiographic map of Nepal (Figure 3). Geologically, the studies of springs were conducted in the dominant rocks of Nepal Himalaya, such as Shale, Slate, Phyllite, Schist, Gneiss, Mudstone, Siltstone, Sandstone, Quartzite, from Siwalik, Lesser Himalaya, and Higher Himalaya.

The gathered information was synthesized and interpreted after reviewing available documents and articles identify common trends, knowledge gaps, significant findings, and other pertinent details related to springs in Nepal. The findings and insights were compiled and organized from the review into a cohesive article on groundwater springs in Nepal. The studies collected primary data using standardized forms, including a spring inventory, geological inventory, focus group discussions (FGD), and key informant interviews (KII), ensuring consistency and reliability in the data collection process. The Geographic Information System (GIS) and Remote Sensing (RS) tools help identify potential recharge zones and aid in

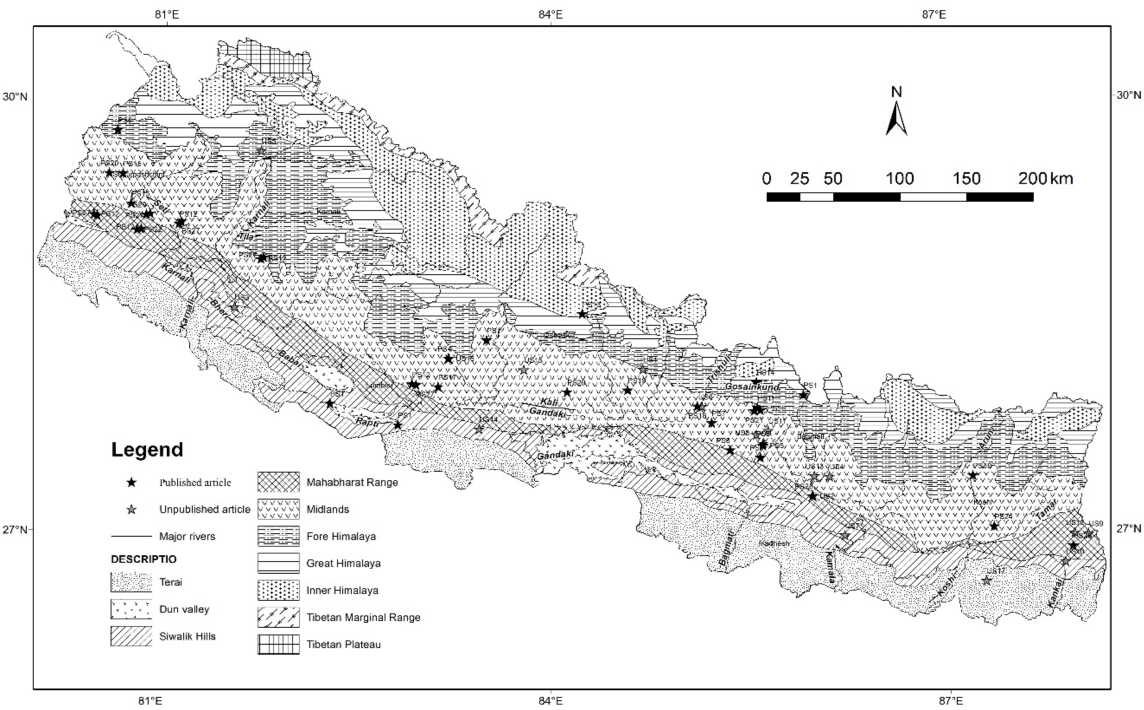

Fig. 3: Springs distribution study in Nepal's Physiography (Dhital, 2015).

better planning for increasing recharge potential. The managed potential recharge areas and spring water sources direct the future water availability to fulfil the increasing water need of the communities (Shrestha, 2020).

The potential solutions to water scarcity in the rural watersheds of Nepal conclude that catchment protection can effectively prevent contaminants from being deposited in the springs and groundwater recharge areas. In closely populated areas, delineation of recharge zones may be impracticable, but careful management of these zones is possible with the involvement of communities. The paper emphasizes the need for a collaborative approach to maximize access to critical research and promote sustainable scholarly publishing (Merz et al., 2003).

The integrated approach of geospatial and field exploration techniques effectively assesses potential groundwater zones in a hard-rock aquifer Himalayan watershed (Sapkota et al., 2021). The groundwater spring potential validation is successful, implying that the method can be replicated in a similar biophysical environment (Ghimire et al., 2019). The hydrologic modelling was carried out in a spring catchment of western Nepal to understand the changing hydrological processes. The study suggests that understanding the likely response of hydrologic variables to potential future climate scenarios is critical for water resource management (K.C. et al., 2021).

An opinion paper Yadav (2018) discusses challenges, governance, and management of groundwater resources in Nepal. It highlights the importance of sustainable management of groundwater resources and the need for policy reorientation to address potential vulnerabilities of groundwater to climate change, changing economy, and diverse social contexts.

Dahal et al. (2021) argue that a combined set of policies and practices prioritizing the sustainability of Himalayan spring sources could have a transformative impact. Regarding management-related studies of springs, Rijal (2016) emphasized a springshed approach to ensure water security in hilly communities. The author mentioned that springshed ('muladhar') should address springs rather than watershed ('jaladhar') to focus on spring revival and conservation. As such, the study was conducted in springshed approach by Lamichhane et al., (2020).

Similarly, the importance of hydrogeological science in managing watersheds, springsheds, and groundwater is demonstrated in the manual of protocol for reviving springs by Shrestha et al. (2018). It describes that the location and extent of recharge areas, where water enters the ground and replenishes aquifers, are determined by local hydrogeology rather than administrative or socio-economic boundaries. The perspective requires a paradigm shift in how we think about watersheds and springsheds.

Spring water discharge

The studies incorporated various techniques to measure spring discharge, namely the bucket stopwatch, area velocity, and water level drop methods were used to obtain discharge. Several studies classified springs into different types to comprehensively understand spring behavior across different time periods and locations. The widely adopted classifications of Tolman (1937) include Depression, Fracture, Contact, Fault, and Karst springs. Many studies incorporated Meinzer (1923) for the springs categorization based on their discharge, emphasizing the importance of considering the variability of spring discharge. The studied springs are categorized as constant, semi-constant, and variable springs as adapted by Pokhrel and Rijal (2020).

Groundwater is available in most parts of the country, but the amount and depth vary from place to place (Shrestha et al., 2018). The study by Ghimire et al. (2019) identified 11 influencing factors related to spring occurrence and groundwater movement and surveyed 412 springs in the study area. The water stress in the Rel Gad watershed is evident, accentuating the proper recharge area management. Only 16 percent of the total watershed area is under a remarkably high recharge potential zone, while 31 percent falls under minimal recharge potential. The average spring discharge is higher on the Northern Slope but lower on the southern slope (Shrestha, 2020). The 2015 Nepal earthquake had a huge and immediate impact on the water volume of the springs in the study, with an drying effect about 18% of the springs (Chapagain et al., 2019). Moreover, the discharge of springs increases highly after monsoon indicating that springs are highly dependent on precipitation (K.C. and Rijal, 2017).

Spring water quality

The in-situ water quality parameters employed in studies include EC (Electrical Conductivity), pH, Temperature, TDS (Total Dissolved Solids), and Salinity. Davis and DeWiest (1966) provided a classification system that divides water into fresh, brackish, salty and brine water to assess the TDS levels. Similarly, the classification of water based on EC, as proposed by Detay (1997), consists of six classes: very weakly, weakly, slightly, moderately, highly, and excessively mineralized water.

Piper (1944) presents a visual method for separating and analyzing dissolved substances in water. It helps study the origins of these constituents, changes in water characteristics as it moves through an area, and other geochemical issues. The primary factors governing the chemical composition of water mechanisms are atmospheric precipitation, geological influence, and the evaporation-crystallization process (Gibbs, 1970). The Stiff (1951) pattern is a visual representation of chemical analyses to illustrate the primary ion composition of a water sample. Bhattarai (1980) discusses the investigations on four thermal springs in Nepal of tectonic origin close to and south of either the Main Central Thrust or the Main Boundary Fault. Thermal waters outflowing in Greater Himalaya Sequence show a lower HCO_3 interpreted as reflecting changes in CO_2 outgassing possibly related to the 25 April 2015 Gorkha earthquake (Ghezzi et al., 2019).

The water quality of spring resources of the Badigad Catchment was found under the permissible limit of the National Standard for Drinking and Irrigation (NSDI) and WHO standards for drinking and irrigation water. Spring originated from non-carbonate rocks have slightly lower value of chemical parameters than those from the carbonate rocks (Bhusal and Gyawali, 2015). Dumaru et al. (2021); Tiwari et al. (2020); Thapa et al. (2020); Shrestha et al. (2023); Silwal et al. (2022) and Pantha et al. (2022) did suitability analysis to evaluate the quality and potential usability of spring water for drinking and irrigation purposes by using WQI and compare with national standards.

DISCUSSION

The Midland region of Nepal covers a total area of 43,141 sq. km. (Dhital, 2015) as Figure 3, the average density of the springs in the studied area is 2.57 springs per sq. km. Based on this information, it is estimated that there are approximately 111,045 springs in the Midland of Nepal.

Spring water quality and water quantity studies

Out of 30 PS, 11 discussed spring discharge quantity and 10 discussed spring water quality, and all 17 UPS included water quality and quantity. However, most scientific studies focus on quantifying spring water and other assessed spring water quality. Scientific measurements and statistical analyses provided measurable insights into spring characterizations.

Semi-quantitative studies

Out of 47 articles, 8 PS and 17 UPS discussed potential groundwater zones incorporating the different thematic layers as discussed below. Within 17 UPS, one had discussed the water poverty index using the parameters resource, use, access, capacity, and environment. Groundwater potential studies have been conducted continuously in Nepal, considering various factors contributing to increasing groundwater spring potentiality. It is found that the role of such factors assigned solely depends on the site-specific condition and authors' observation.

The validated influencing factors utilized in 14 UPS and 3 PS are hydrogeomorphology, geomorphology, water ratio index, topographic wetness index, rainfall, drainage density, degree of slope, degree of slope aspect, relative relief, elevation, geology, lineament, soil thickness, land use/land cover,

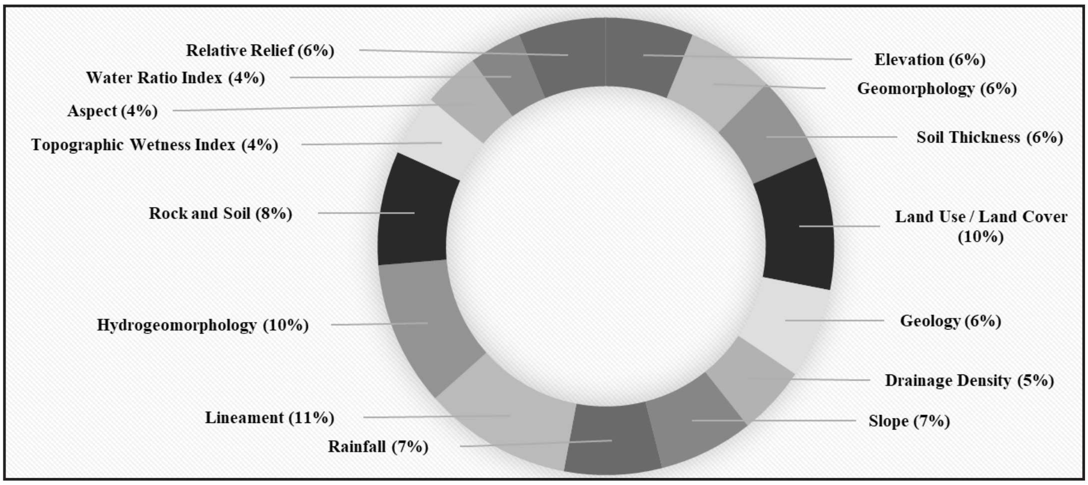

Fig. 4: Influencing factors of groundwater potential from the research of Nepal

and rock-soil characteristics (Figure 4). Each aspect carries a specific weightage, reflecting its significance in determining the suitability of an area for groundwater development and management.

Scientific data and social information of springs

The studies of springs utilized both scientific and social information. The most adapted parameters of scientific studies are hydrogeological mapping, groundwater potential zonation using GIS and RS applied in 25 articles and isotopes in 1 article (Matheswaran et al., 2019). Estimating the water quality index by applying laboratory and in-situ analyses of water samples are parameters to describe spring water quality. The scientific aspect focuses on understanding the physical processes, hydrogeological characteristics, and environmental factors influencing springs.

The societal parameters are found to be very crucial as springs hold cultural, historical, and socio-economic significance for communities relying on them for their water needs. It includes recognizing the cultural values attached to springs, the customary water use and management practices, and the social dynamics of water access and distribution. The tools for social surveys are Questionnaire, FGD, and KII. The spring inventory done by various researchers Adhikari et al. (2021) and Gurung et al. (2019) of large number of springs i.e., 4,222 from five different watersheds in Nepal incorporating social sciences is significant spring research in Nepal. (Poudel and Duex, 2017) recommends for building community capacity for water sustainability and climate change adaptation.

Drinking and other uses of spring water

Springs play an important role in providing drinking water to communities, particularly in rural areas, where they are often the primary source of water supply. The quality and quantity of water from springs are critical factors in determining their suitability for drinking. Springs have multiple uses beyond drinking water. They are vital water sources for agricultural irrigation, livestock watering, and other domestic and commercial activities. Understanding the different water demands and usage patterns associated with springs is crucial for effective water resource management.

Project-dependent and academic studies of spring

Academic studies focus on advancing scientific knowledge and understanding of springs, employing rigorous methodologies and scientific approaches to investigate various aspects such as hydrogeology, water quality, and hydrological processes. These studies contribute to the theoretical understanding of springs, expanding the scientific knowledge base.

Project-based studies are initiated by governmental organizations, non-governmental organizations, or development projects to assess springs' availability, sustainability, and management for various purposes such as drinking water supply, irrigation, or ecosystem preservation. Practical considerations and specific objectives drive the studies of springs. Dhakal et al. (2021) mentioned springshed management practices, including improved forest management, rainwater harvesting, and awareness campaigns, are recommended to enhance water security and building socio-ecological resilience in the region.

CONCLUSIONS

A recent trend in spring studies in Nepal is revealed from reviewing and in-depth analysis of publications on springs and spring water resources. This trend primarily focuses on fundamental parameters of springs such as spring discharge, in-situ physio-chemical parameters and some chemical water quality parameters. Besides that, the societal status of spring water users is included in some studies. In addition, conservation and management-related studies have also identified applying a concept of the springshed approach. However, origin, seasonal dynamics, anthropogenic impact on spring origin, and gender issues related to spring water uses are rarely focused on in these studies. The science of spring hydrogeology linking their origin with aquifers and their contribution to environmental flow and base flow for sustaining ecosystems in hill and mountain regions of Nepal Himalaya is far less focused.

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ANNEXURES

Annex 1: Number of studied springs of PS and corresponding authors.

Area code	No. of springs studied	Author(s)	Area code	No. of springs studied	Author(s)
PS1	4	(Bhattarai, 1980)	PS17	102	(Thapa et al., 2020)
PS3	40	(Dhakal et al., 2021)	PS18	69	(Lamichhane et al., 2020)
PS4	30	(Bhusal and Gyawali, 2015)	PS19	44	(Pokhrel and Rijal, 2020)
PS5	286	(Sharma et al., 2016)	PS20	90	(S. Shrestha, 2020)
PS6	57	(P. C. K.C. and Rijal, 2017)	PS21	18	(Khadka and Rijal, 2020)
PS7	41	(Poudel and Duex, 2017)	PS22	160	(Dumaru et al., 2021)
PS11	412	(Chapagain et al., 2019)	PS24	97	(ICIMOD, 2021)
PS12	155	(Gurung et al., 2019)	PS25	61	(Sapkota et al., 2021)
PS13	9	(Ghezzi et al., 2019)	PS27	4222	(Adhikari et al., 2021)
PS14	412	(Ghimire et al., 2019)	PS28	147	(Silwal et al., 2022)
PS15	7	(Matheswaran et al., 2019)	PS29	3	(Pantha et al., 2022)
PS16	57	(Tiwari et al., 2020)	PS30	85	(A. Shrestha et al., 2023)

Annex 2: Number of studied springs of UPS and corresponding authors.

Area code	No. of springs studied	Author(s)	Area code	No. of springs studied	Author(s)
UPS1	28	(Gautam, 2017)	UPS10	10	(Shah, 2021)
UPS2	107	(Adhikari, 2017)	UPS11	15	(Pandey, 2021)
UPS3	8	(B.C., 2018)	UPS12	147	(Karkee, 2021)
UPS4	33	(Khadka, 2018)	UPS13	12	(Bhattarai, 2021)
UPS5	8	(Sunar, 2020)	UPS14	11	(Maharjan, 2021)
UPS6	80	(Aryal, 2021)	UPS15	23	(Aryal, 2022)
UPS7	18	(Magar, 2021)	UPS16	122	(Sapkota, 2022)
UPS8	15	(Dhungana, 2021)	UPS17	20	(Dahal, 2022)
UPS9	129	(Acharya, 2021)			

Annex 3: Water Quality, Water Quantity, and Semi Quantitative-Qualitative categories of PS.

Published Studies (PS)		
Water Quality	**Water Quantity**	**Semi Quantitative-Qualitative**
(Bhattarai, 1980)	(Sharma et al., 2016)	(Merz et al., 2003)
(Bhusal and Gyawali, 2015)	(K.C. and Rijal, 2017)	(Yadav, 2018)
(Poudel and Duex, 2017)	(Chapagain et al., 2019)	(Shrestha et al., 2018)
(Ghezzi et al., 2019)	(Pokhrel and Rijal, 2020)	(Shrestha et al., 2018)
(Gurung et al., 2019)	(Lamichhane et al., 2020)	(Ghimire et al., 2019)
(Tiwari et al., 2020)	(Khadka and Rijal, 2020)	(Matheswaran et al., 2019)
(Thapa et al., 2020)	(Dhakal et al., 2021)	(Shrestha, 2020)
(Dumaru et al., 2021)	(ICIMOD, 2021)	(Sapkota et al., 2021)
(Pantha et al., 2022)	(K.C. et al., 2021)	(Dahal et al., 2021)
(Shrestha et al., 2023)	(Adhikari et al., 2021)	(Rijal, 2016)
	(Silwal et al., 2022)	