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The degradation of spring water resources in Nepal: some policy gaps

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ABSTRACT

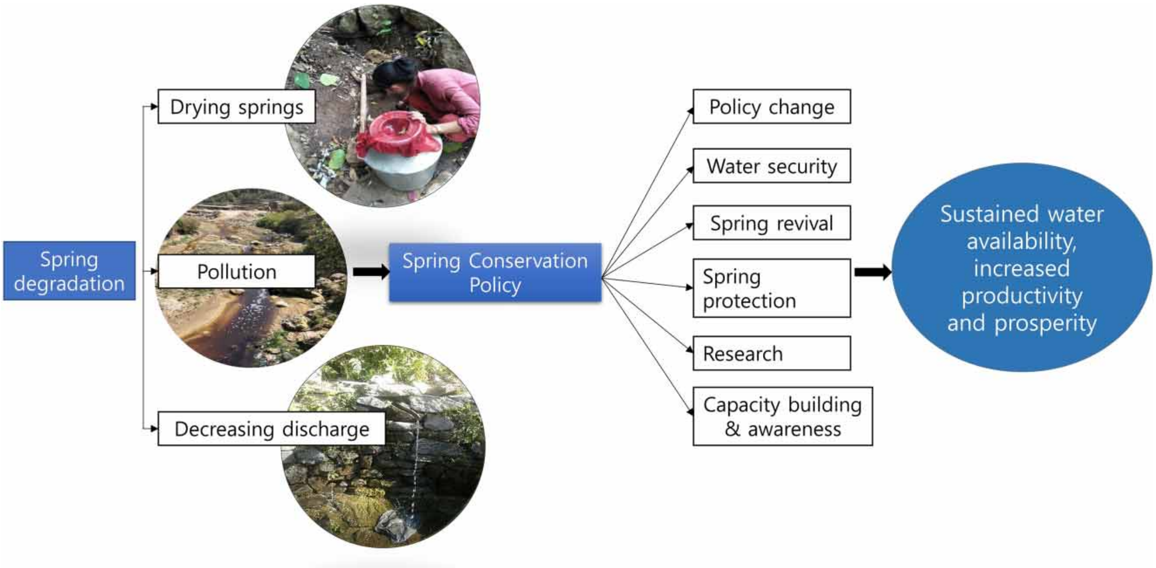
In this study, first, we conducted a case study to understand the spring status in a semi-urban area, then synthesized the knowledge acquired so far, of nationwide springs status to highlight the current state and future policy and action implications of spring conservation in Nepal. We found that in 72% of the springs of semi-urban areas, the discharge rate has been decreasing over the past decade. In addition, the springs of such areas were exposed to higher contamination of biological pollutants compared with the rural areas. Synthesis of spring research in Nepal shows that springs of Nepal are degrading at an alarming rate where 16% had already dried up and about 60% have declining discharge, mainly due to declining rainfall, haphazard infrastructure development, and excessive spring resource exploitation. In response to the degrading springs and water crisis, several initiatives have been made, yet they are scattered, focused on limited springs, and not adequate to curb the current rate of spring degradation. We argue that the existing policies that are intended to operate in a top-down approach at the basin and watershed level are not effective in addressing local water issues at the springshed level.

Key words: Action, Drying spring, Spring policy, Water crisis, Water pollution

HIGHLIGHTS

- The status of spring degradation in Nepal is comprehensively explored.
- The spring survey results showed that 72% of the springs had a decreased flow.
- Loopholes in existing policies and efforts for spring conservation are identified.
- Key considerations for formulating a dedicated spring conservation policy have been suggested.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Undoubtedly, water is considered a fundamental basis for sustaining life and maintaining a sustainable environment (Singh *et al.*, 2020). Globally, 97% of total water is concentrated in saline water and only 3% of the water is freshwater (Cassardo & Jones, 2011). Out of this, less than 1% of fresh water is available for ecosystems and humans (Gleick, 1993; Figuères *et al.*, 2003). However, water resources are unevenly distributed and are on the verge of diminishing day by day (Yano *et al.*, 2015). The availability, as well as the quality of water resources, are important factors for human society and the environment (Gurung *et al.*, 2019a). Despite being one of the world's richest water resource countries, Nepal has been experiencing problems related to water access and quality (Gurung *et al.*, 2019a; Adhikari *et al.*, 2021b). Natural springs and small rivers are regarded as the major sources of water for drinking, livestock feeding, irrigation, and other purposes in the Middle Hills of Nepal (Chapagain *et al.*, 2019). Thus, in the mountains and hills of Nepal, out of 13 million people, approximately 80% of the total population relies on spring water as the primary source of water (Tambe *et al.*, 2012).

Springs are unique and diverse, being formed by a natural process where the complex interaction of ground and surface water occurs (Gornakov *et al.*, 2002). The origination points of the spring water are fractures, faults, or rock contact through pressure (Menció *et al.*, 2011; Thapa *et al.*, 2020). The availability of natural springs depends on the local settings (Gornakov *et al.*, 2002). In hard rocks, the geological parameters are favorable for the occurrence of springs (Yechezkel *et al.*, 2021). Their occurrence also varies with time, climatic conditions, topography, rainfall, and land use/land cover type (Yano *et al.*, 2015; Chapagain *et al.*, 2019).

In the middle mountains of Nepal with various infrastructural developments, the natural springs are being neglected and the catchments of the springs are degraded, disrupting the hillslope hydrology and leading to the drying up of springs or reduction of the flow regime during the dry months (Gurung & Oh, 2012; Gurung *et al.*, 2019a; Adhikari *et al.*, 2021b). Also, the massive earthquake in 2015 seriously disrupted the local water budget as evidenced by the drying up of over 5,000 groundwater streams (Ghimire *et al.*, 2019). In such a situation, the investigation of the condition of the natural springs becomes an important matter to rethink the restoration of the water resources and maintain the balance of the water table. Access to adequate and clean water is a right of every citizen and will be a great contributing factor to improving health and better productivity (Maharjan, 2008).

Though spring water is one of the major water resources, it could also be a source of contamination if regular monitoring of the spring is not done (Adhikari *et al.*, 2021b). Springwater has natural water quality and is extremely vulnerable to any type of pollution caused by human activities and the influence of the change of climate on the quantity and quality of surface runoff feeding groundwater (Al-Barwary *et al.*, 2018). The water quality of the natural springs is an important issue, especially in the least developed countries like Nepal. Different geological, hydrological, physiographical, ecological, and anthropogenic influences within the groundwater and aquifer materials affect the water's chemical quality (Sharma *et al.*, 2016; Adhikari *et al*. 2021a). It also aids water resource management by identifying the water's quality and suitability for different purposes (Khadka & Rijal, 2020). A geographic information system (GIS) could be a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision-making in several areas including engineering and environmental fields (Johnson, 2016). The use of GIS technology has simplified the assessment of natural resources and environmental concerns including water resources mapping and assessment (Balakrishnan *et al.*, 2011).

In recent years, spring studies are concentrated in mid-hills areas. The state of springs in rural areas can be generalized and it has been well established that springs of rural areas are degrading faster than expected. However, there are very limited studies on the springs of the urban and semi-urban areas and the trend and pattern of such springs are yet to be understood. The urban municipalities have carried out various developmental activities, including the expansion and construction of roadways, and other physical structures. However, the actual quantification and mapping of the water resources are lacking which could be good assets for the development of the municipality. Therefore, to understand the biophysical, socioeconomic, and institutional setting, various qualitative and quantitative studies are required for water-related issues (Poudel & Duex, 2017). The study alone with the quantification of the available water resources is an important factor for determining the capacity of the water resources to fulfill the demand of water supply in the municipality.

Thus, the main objective of this paper is to (i) study the status of springs in the semi-urban area (Chandragiri Municipality) by assessing different spring attributes including discharge trend, physicochemical, and microbiological parameters, (ii) synthesize the knowledge of the nationwide spring status, discharge trend, and dynamics, and existing policies on local water resources, and (iii) highlight the current state and future policy and action implications for springs revitalization and conservation in Nepal. This study will help decision-makers and planners understand the major concerns of spring degradation and facilitate the policy formulation and effective implementation of comprehensive water resources management efforts in Nepal.

2. MATERIALS AND METHODS

2.1. Case study site

For understanding the status of springs in a semi-urban area, Chandragiri Municipality was chosen. The Municipality is located in the southwest part of Kathmandu valley in Bagmati Province (Figure 1). It was formed by merging 11 former village development committees (VDCs) in 2014. The total area of the municipality is 43.92 km^2. This municipality lies in 27°43′36.486″ N in the North, 27°32′45.029″ N in the South, 85°16′39.509″ E in the East, and 85° 11′8.685″ E in the West. It lies in the subtropical climate zone (1,000–2,000 m) and Deciduous Monsoon Forest Zone (1,200–2,100 m). The total population of the municipality based on Census 2011 was 85,198 with an annual growth of 4.44% (Government of Nepal, 2019). Since the municipality is close to the Kathmandu Metropolitan City, it is the gateway to the capital city. The municipality is rich in natural resources and also passes through the Prithvi Highway, thus there is a great opportunity for development activities.

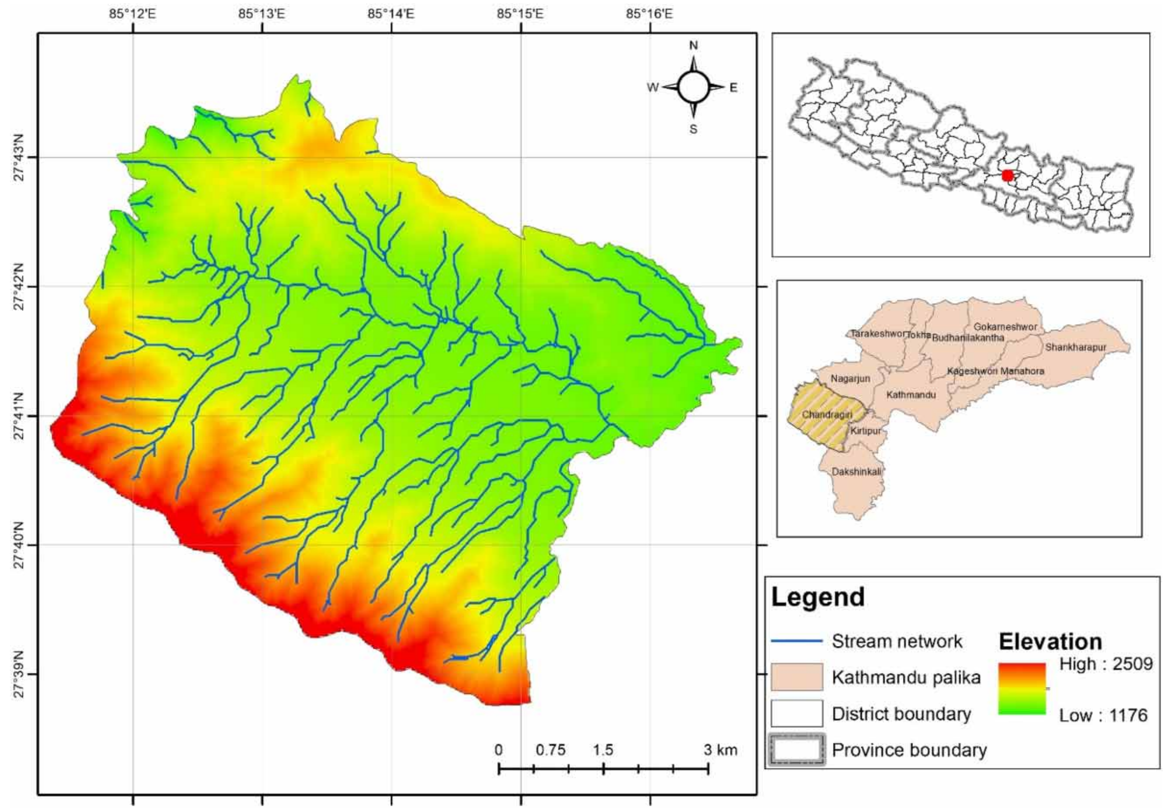


Fig. 1 | Study area, Chandragiri Municipality.

2.2. Research strategy

For assessing the status of springs in a semi-urban area, we employed a multipronged strategy for data collection which includes a preliminary field visit, transect survey, perception survey, spring mapping, observation and measurements of springs attributes, sample water collection, and laboratory analysis. For meta-analysis of the pieces of literature, first, we collected published literature in the form of journal articles, reports, books, and policy documents by using keywords like 'springs mapping', 'spring status', 'spring water quality', and 'spring conservation' in Google scholar, Scopus, and PubMed research databases. The literature published before April 2022 was considered for this study. In this way, we collected about 60 reference materials. Among them, 25 works of literature that were relevant to the Nepalese context were reviewed thoroughly using a defined review framework in Microsoft Excel 2019 and the information was synthesized to provide updated information on the springs of Nepal.

2.3. Assessment of springs of the semi-urban area

A thorough walk in the municipality was required for the inclusion of all possible springs throughout the municipality. The location of the spring throughout the municipality cannot be identified by a new surveyor on a single visit. Thus, the preliminary visit was made to identify the local person who could help in mapping the possible numbers of springs in the municipality. We selected seven local women working in the cooperative as field enumerators to guide the field survey. We chose these women as they were typically the collectors, users, and managers of household and community water resources. Women are primarily responsible for performing traditional household chores in Nepal.

During the field visit, the survey was conducted by thoroughly walking within each ward of the municipality together with the local person. An inventory of all the natural springs in the study area was done using global positioning system (GPS) during the field survey. The discharge measurement of the springs was done using the methodology described elsewhere (Herschy, 1993). During the field visit, different attributes related to springs such as types of springs, condition of spring, discharge rate, distance from the settlements, the surrounding land use, purpose of water use, and the status of the springs were studied. Additionally, the pattern of flow in the spring water for the past 10 years was cross-examined with the local people using an open-ended survey questionnaire. Table 1 shows the methods of discharge measurements at different types of water resources in the research area.

Similarly, the physical parameter of the water including pH, temperature, total dissolved solids (TDS), and electrical conductivity (EC) was measured at the study site. To perform further analysis of the chemical and microbiological parameters, field sampling was carried out by assuming 15% of each category of springs (five spouts, two ponds, one stream, two kuwa, and nine stone spouts) and taken for water quality test in the laboratory of the Central Department of Environmental Science (CDES), Tribhuvan University. Specifically, the water quality test was planned for drinking water purposes and included parameters such as chloride, alkalinity, free CO_2, dissolved oxygen (DO), total hardness, magnesium hardness, calcium hardness, phosphorus (PO_4), ammonia (NH_3), nitrate (NO_3^-), and coliform. Temperature, TDS, and EC were measured by the conductivity meter (Milwaukee EC59) and pH was measured using the pH meter (Milwaukee pH55). Alkalinity, chloride, total hardness, nitrate, ammonia, phosphate, calcium hardness, magnesium hardness, free CO_2, DO, and coliform were measured according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). A spectrophotometer (SSIUV2101) was used for colorimetric analysis.

2.4. Data analysis

The collected GPS coordinates of natural springs were mapped using the Arc GIS 10.8 software. A spring distribution map was prepared that depicts the actual position of the spring in the real field. Similarly, the physicochemical and microbiological parameters of the water were analyzed using MS Excel 2019 using descriptive analysis and frequency distribution. For the systematic review, a well-defined review and data collection framework were developed and the collected information was analyzed using descriptive analysis and frequency distribution. The resulting output was expressed in the form of charts and tables in the Results and Discussion section.

Table 1 | Methods for discharge measurements.

Water resource types	Method	Parameters required	Instrument required
Running/flowing springs and streams	Floatation method	Length of stream section (Point A to Point B); cross-section area, the width of the channel, depth of the channel; time taken to float from A to B	Measuring tape, tennis ball
Tapped springs, channels	Bucket method	Volume to the bucket; time taken to fill the bucket	Bucket of known volume
Stagnant springs (kuwa, ponds, wells)	Volumetric method and perception-based	Dimension of the spring (length, breadth, depth); watermark level marking	Measuring tape

3. RESULTS AND DISCUSSION

3.1. Spring distribution and status in the semi-urban area

A total of 140 springs were spotted in different wards of the Chandragiri Municipality. Altogether five different types of springs were identified during the field study, namely stone spout, spout, kuwa, stream (river), and pond. The majority of the springs were of stone spout type representing 39.29%. Kuwa, the traditional water drinking source, represents only 6.43%, while the spout, pond, and river represent 30, 13.57, and 10.71%, respectively. Figure 2 shows the different types of water resources available in the Chandragiri Municipality. The terminology between stone spout and spout is quite confusing. Generally, a stone spout refers to the traditional stone-carved free-flowing spring with the animal structure carved at the spout, whereas a spout refers to a free-flowing spring with a normal stone and concrete structure. Stream refers to the rivers and ponds refer to the depression where the water sources are available. The kuwa refers to the shallow pit dug to collect water that does not flow freely but seeps slowly out of the groundwater. This is the most common type of water resource that was used in the past.

The status and distribution of springs are given in Figure 3. In recent years, the discharge condition has changed in the spring sources. In 15% of the mapped springs, the water flow has dried up. The main reason for this drying may be the increasing urbanization and lack of groundwater recharge. In 14.3% of the springs, the water flow has become stagnant, while in the remaining 70.7%, the water is flowing. In the past decade, the agricultural land has been converted into settlement areas thereby disturbing the water table in the surrounding. The roadways are also constructed and expanded to all wards in the municipality. Traditional water recharging sources such as ponds and wallows have disappeared in the communities. Due to the increasing construction of infrastructures, particularly settlement areas, the groundwater is drawn beyond its carrying capacity in the densely populated wards. On

Fig. 2 | Springs of semi-urban areas. (a) Stone spout, (b) spout, (c) kuwa, and (d) pond.

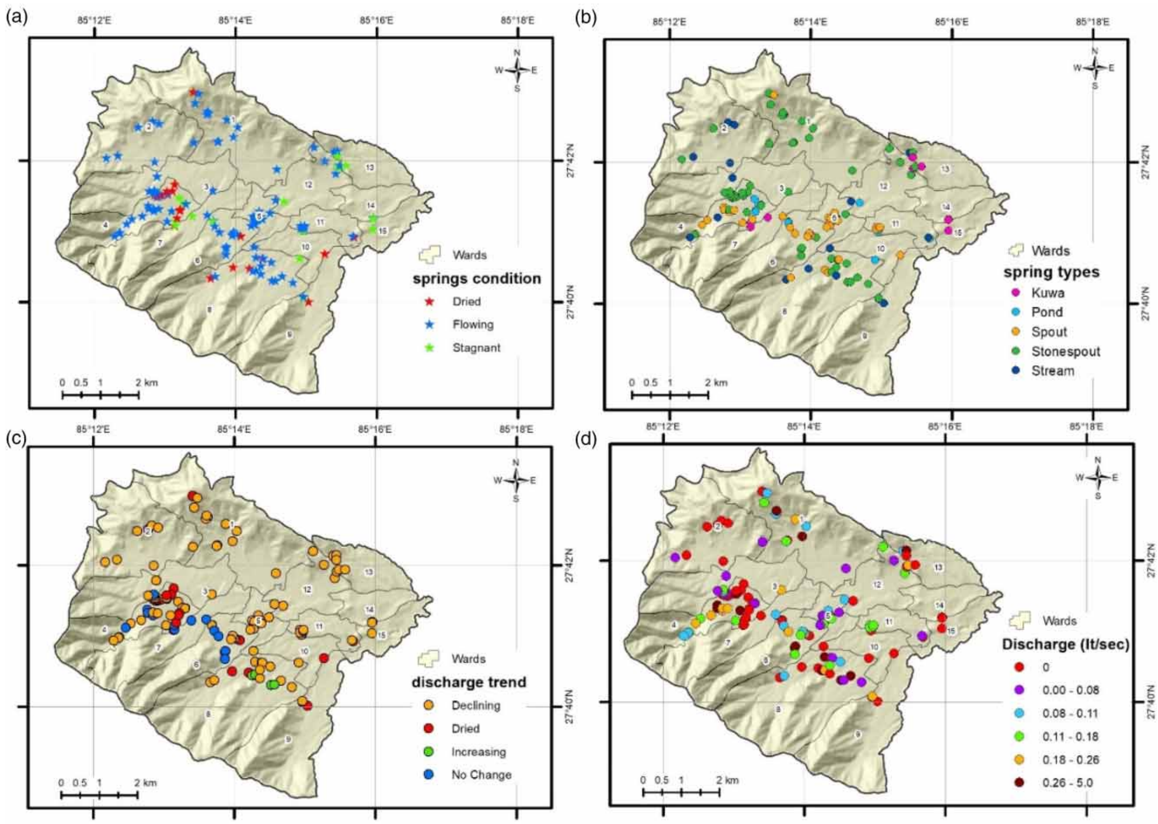


Fig. 3 | (a) Spring distribution based on flow status, (b) types of spring sources mapped, (c) discharge trend, and (d) discharge rate of springs in Chandragiri Municipality.

the other hand, the concrete infrastructure impedes the infiltration rate that ultimately reduces the groundwater recharge and thus, water flow has decreased in the existing water resources. This indicates that the existing water resources need special attention for conservation. A proper management plan should be made and implemented within the municipality for better use of existing water resources.

In this study, we analyzed the spring structure and the land use type in the surroundings. Figure 4 shows the spring structure in the Chandragiri Municipality. The study revealed that almost 72.86% of the spring sources have concrete structures followed by 11.43% natural and 9.29% semi-concrete, while a small portion of the springs has a pipeline structure, i.e. 6.43%. It was found that 44% of the springs are located near the settlement area followed by 17.14% forests and settlement and 2.8% settlement and agriculture. Similar studies on the distribution of spring sources showed the primary land use types around the spring to be forests (53.6%), cropland (34.1%), and bushes (12.3%) (Poudel & Duex, 2017). The studies conducted in Melamchi Region, Central Nepal have reported that the land use pattern around the spring was dominated by forest land (47%), bush/grassland (24%), agricultural land (13%), and barren land (4%) (Chapagain *et al.*, 2019). But the result from the study site showed the highest percent of springs are of concrete type structure and are identified in the vicinity of settlement type land use. The primary reason for this might be the increasing urbanization and proximity to the capital city, Kathmandu.

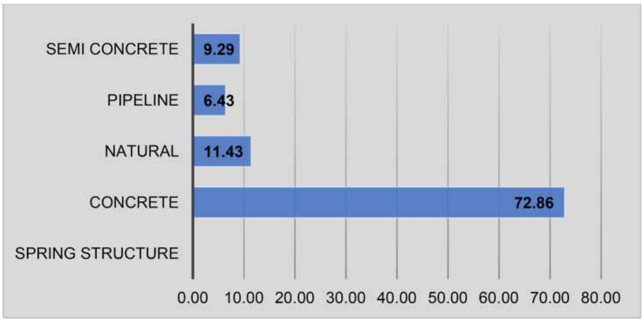


Fig. 4 | Different conditions of spring.

Spring discharge is a critical parameter for the suitable development and management of the spring (Joshi, 2006; Burnett *et al.*, 2020). Spring has provided water for the revival of the traditional source of water as well as to keep the rivers and ponds alive throughout the year (Taloor *et al.*, 2020). Based on the perception of the local people, it was observed that the discharge rate in the spring has been gradually declining. The findings revealed that, in 72.14% of the springs, the water discharge has been decreasing. Approximately 13.57% of the springs have dried up permanently, and in 11.43% of the springs, the water discharge has remained unchanged. Surprisingly in 2.06% of the springs, the water discharge has increased. The main reason for drying up water discharge in the springs may be due to a decrease in the groundwater storage or level due to the increased extraction and lack of spring conservation awareness (Sharma *et al.*, 2016). The discharge rate is also influenced by the uneven rainfall pattern (Negi & Joshi, 2004; Thapa *et al.*, 2020). In the study site, an increase in temperature and a decrease in rainfall patterns have been reported (Magar & Adhikari, 2019). The pattern of decreasing water discharge in the spring is becoming a common phenomenon in the mountains (Tambe *et al.*, 2012; Agarwal *et al.*, 2015; Adhikari *et al.*, 2021a, 2021b). The local people were asked about the uses of water resources in the Chandragiri Municipality. The local respondents replied that 49% of the spring has drinkable water and people are using them for their daily drinking purposes.

3.2. Assessment of semi-urban spring water quality

After mapping the springs within the Chandragiri Municipality, the water samples from 19 sites were collected and tested with physicochemical and microbiological parameters. Table 2 shows the descriptive results of the different analyzed water quality parameters. The result showed that the temperature of the water sample ranged from 17.3 to 21.8 °C with a mean value of 19.25 °C. Generally, the temperature does not have any guideline value, however, the obtained value should be within the acceptable limit. Cool water is more potable and preferred by people. High water temperature enhances the growth of microorganisms and leads to the spreading of the chemical reaction in water, reduces the solubility of gas, and amplifies the taste and odor (Talaiekhozani *et al.*, 2016). pH is one of the most influencing parameters of a chemical reaction within the water (Sharma *et al.*, 2013). pH indicates the acidic or basic nature of water. In this study, the pH of the spring water varies from 6.9 to 7.4 with a mean value of 7.18, which indicates the water is neutral to slightly alkaline. The drinking water quality standard for pH in Nepal Drinking Water Quality Standard (NDWQS) is in the range of 6.5–8.5. All the spring water has a pH value within the standard provided by NDWQS.

The findings showed that there is a great fluctuation in the EC and TDS of the sampled water. The EC ranged from 145 to 718 μS/cm with a mean value of 345 μS/cm, while the TDS was detected in the range of 73–395 ppm

Table 2 | Descriptive statistics of spring water quality.

Parameters	Minimum	Maximum	Mean	Standard Deviation	NDWQS
pH	6.9	7.4	7.18	0.15	6.5–8.5
TDS (ppm)	73	359	170.74	78.74	1,000
EC (μs/cm)	145	718	345.00	157.68	1,500
Temperature (°C)	17.3	21.8	19.25	1.28	
Alkalinity (mg/L)	10	75	38.47	18.05	
Total hardness (mg/L)	50	318	165.26	67.92	500
Calcium hardness (mg/L)	29.6	137.87	71.01	30.75	
Magnesium hardness (mg/L)	2.76	40.35	21.18	10.00	
Chloride (mg/L)	14.2	183.18	51.72	41.17	250
Free CO_2 (mg/L)	13.2	35.2	20.15	5.94	
Ammonia (mg/L)	0.24	0.26	0.26	0.01	1.5
Phosphorus (mg/L)	0.0029	0.32	0.18	0.09	
Nitrate (mg/L)	0.04	28.5	4.32	6.66	50
DO (mg/L)	3.21	7.69	6.22	1.41	
Total coliform	7	132	50.86	33.29	0

with a mean value of 170.74 ppm. However, all the spring water has a TDS and EC value within the standard provided by the NDWQS. The higher concentration and the great fluctuation of EC and TDS might be due to the presence of a higher concentration of organic and inorganic solids (Tiwari *et al.*, 2020). Usually, the TDS and EC values remained within the acceptable standard levels prescribed by the World Health Organization (WHO) (Khadka & Rijal, 2020; Thapa *et al.*, 2020).

The total hardness in spring water was found to be 50–380 mg/L with a mean value of 165.26 mg/L, suggesting a higher concentration of soluble calcium and magnesium salts due to higher rock water interaction and lithology (Belkhiri *et al.*, 2011). The fluctuating DO levels in the water sample may affect the biological, chemical, and physical processes of the water (Batool, 2018). The value of DO ranged from 3.21 to 7.69 mg/L with a mean value of 6.22. Chloride content ranged from 14.2 to 183.18 mg/L with a mean value of 51.72 mg/L. Furthermore, the free CO_2 ranged from 13.2 to 35.2 mg/L with a mean value of 20.15 mg/L.

The sampled spring water contains a much lower amount of ammonia and phosphate. However, the concentration of nitrate was found to be relatively high in a few samples. The maximum concentration of 28 ppm of nitrate was detected in this study. The main reason for the nitrate pollution may be the settlement and agricultural runoff. The nitrate concentration depends on the occurrence of rainfall and surrounding land-use patterns (Menció *et al.*, 2011). Springs are considered representative of the uppermost groundwater flow path and therefore revealing of soil dynamics concerning nitrate occurrence, attenuation, and further migration to aquifers (Joshi, 2006; Sharma *et al.*, 2019). The fecal indicator of the spring water was not at an acceptable level. The water quality study at the spring of the Thulokhola watershed showed a similar result indicating that the spring water has a high rate of nitrate level and fecal contamination (Poudel & Duex, 2017). The study also suggested poor surface water quality because of sediments, nutrients, and pathogens (Bwire *et al.*, 2020; Sarkar *et al.*, 2022).

Though the physicochemical parameter was satisfactory, all the springs were contaminated with fecal indicator bacteria. This indicates that the water resources were suffering from anthropogenic activities. A similar study revealed that the authors observed a wide variation in the microbial levels recorded in the springs (Daghara *et al.*, 2019). The presence of coliform in the water sample indicates bacterial contamination which might be due to the sewage contamination in the springs and the increased influence of humans as most of the springs were in the vicinity of settlement (Haruna *et al.*, 2005; Batool, 2018; Sarkar *et al.*, 2022).

3.3. State of springs in Nepal

It has not been long since spring research in Nepal has received much attention. Spring research in Nepal was initiated by ICIMOD in 2003 (Merz *et al.*, 2003a, 2003b). Since then, several studies have been carried out. The studies are mostly focused on mapping springs and understanding the spring status in terms of discharge trend (Dhakal *et al.*, 2021; Rijal, 2016; Chapagain *et al.*, 2019; Gurung *et al.*, 2019a; Pandit *et al.*, 2019; Adhikari *et al.*, 2021b), exploring the causes of spring degradation (Dhakal *et al.*, 2021; Sharma *et al.*, 2016; Poudel & Duex, 2017), water quality assessment (Gurung *et al.*, 2019b; Pandit *et al.*, 2019; Khadka & Rijal, 2020; Thapa *et al.*, 2020; Tiwari *et al.*, 2020) and springs distribution modeling (Ghimire *et al.*, 2019; Pradhan & Shrestha, 2022). Spatially, most of the districts of the mid-hills and lesser Himalaya have been covered for analysis (Table 3).

Methodologically, the majority of the studies are perception-based and have adopted household surveys, questionnaire surveys, focused group discussions (FGDs), and key informant interview methods (Merz *et al.*, 2003a, 2003b; Poudel & Duex, 2017; Adhikari *et al.*, 2021b). Few studies have adopted a combined approach of social survey, and field instrumentation and measurements of spring attributes, such as slope, aspect, discharge, water quality parameters, and biological parameters (Dhakal *et al.*, 2021; Chapagain *et al.*, 2019; Thapa *et al.*, 2020; Adhikari *et al.*, 2021a). Some evidence of the action research initiatives is also documented (Shrestha *et al.*, 2017). However, the outcomes of such action research cannot be tracked as they are scattered in unpublished documents. Unfortunately, long-term spring monitoring in Nepal is lacking until now.

Springs in Nepal are degrading (drying up and decreasing discharge) at an alarming rate. There is sufficient evidence to support this claim. Out of the 5,465 springs studied in 12 different research projects (Table 3), the discharge of 59.8% of the springs has decreased. More alarming is the situation of dried-up springs which shows that 16.1% (1.6–45%) of the springs have dried up over the last decade. The discharge of 23.7% of springs has remained stable. In a separate study conducted by NWCF and ICIMOD in 300 municipalities of Nepal, 74% of the local governments reported cases of dried-up springs (Adhikari *et al.*, 2021b). This implies one out of every three local governments of Nepal has already observed cases of springs drying up. Spring degradation is observed both in rural and urban municipalities.

In the mid-hills of Nepal, the springs are used up as the primary source of water for direct and indirect purposes. Out of all the mapped springs by several studies, at least 66% had been used for different purposes such as drinking, cleaning, livestock feeding, agriculture, and irrigation. Springs remained unused by humans because of their occurrence in inaccessible terrain such as far from the settlements and agricultural land, located inside forested areas or steep rocky hills. Yet, they have a significant contribution to the base flow of stream hydrology, the account of which is largely missing in Nepal. Due to the high dependency of the mountain people on the springs for their livelihood, they are often called 'mountain lifelines' (Valdiya & Bartarya, 1989; Merz *et al.*, 2003a, 2003b; Agarwal *et al.*, 2014).

The degrading condition of these lifelines has highly affected water availability, water security, and human and aquatic health in Nepal (Adhikari *et al.*, 2021b; Nepal *et al.*, 2021). People are forced to drink flooded water (Gurung *et al.*, 2019a), spend more time on drudgeries, and migrate from the villages (Gurung *et al.*, 2019a; Adhikari *et al.* 2021b). Migration has been an ultimate response to severe water scarcity in the mid-hills. However, this is not a sustainable solution as this only increases water demand and scarcity in the migrated areas. If the trend of spring degradation continues, more than 80% of the mid-hill population will have to suffer severely

Table 3 | Summary of spring research in Nepal.

S.No.	References	Major focus	District	Location	No. of studied springs	Dried-up springs (%)	Decreasing discharge (%)	Potential reason for declining discharge and drying up
1	Merz *et al.* (2003a, 2003b)	Water scarcity	Kaverpalanchowk	Jhiku Khola	–	–	–	–
2	Merz *et al.* (2003a, 2003b)	Water scarcity	Dolakha	Yarsa Khola	–	–	–	–
3	Dhakal *et al.* (2021)	Spring mapping, status, and conservation	Lalitpur	Godavari	40	4	–	Migration of people into the region, the increasing demand for water, long-term decline in rainfall, earthquake
4	Rijal (2016)	Springshed conservation	Nepal		–		–	–
5	Sharma *et al*, (2016)	Increasing discharge through research ponds	Kaverpalanchowk	Tinpiple	70	15	–	Increased water consumption, increased extraction, and reduced recharge, land use and other changes, lack of awareness of the link between recharge and spring flow
6	Sharma *et al.* (2016)	Increasing discharge through research ponds	Kaverpalanchowk	Dapcha	174	30	–	–
7	Sharma *et al.* (2016)	Increasing discharge through research ponds	Kaverpalanchowk	Daraune Pokhari	42	45	–	–
8	Chapagain *et al.* (2019)	Spring status and conservation	Sindhupalchok	Melamchi	412	18	30	Late and less winter rainfall, 2015 Earthquake, tunnel construction, haphazard construction of rural roads, decreased effort in water conservation
9	Poudel & Duex (2017)	Spring status	Nuwakot	Thulokhola watershed	41	12.2	73.2	Declining precipitation
10	Shrestha *et al.* (2017)	Reviving springs	Dailekh	Dullu	106	–	19.81	–

(*Continued.*)

Table 3 | Continued

S.No.	References	Major focus	District	Location	No. of studied springs	Dried-up springs (%)	Decreasing discharge (%)	Potential reason for declining discharge and drying up
11	Ghimire *et al.* (2019)	Spring potential zone mapping	Sindhupalchok	Melamchi	–	–	–	–
12	Gurung *et al.* (2019a)	Water scarcity, spring status, and changes	Surkhet, Dadheldhura, Nuwakot, Khotang		–	20	–	–
13	Gurung *et al.* (2019b)	Water quality	Surkhet, Dailekh, Achham, Kalikot, Doti, Kailai, Dadheldhura, Pyuthan, Arghakhanchi, Gulmi	Mid and far-western Nepal – 5 watersheds	–	–	–	Reduced infiltration rates in hills, fluctuating rainfall, uncontrolled road building, the disappearance of traditional ponds, lakes, and wallows, rural infrastructure development without environmental concerns, and source concreting and piping
14	Pandit *et al.* (2019)	Mapping, classification, water quality	Sindhupalchok	Bansbari	41	–	–	–
15	Khadka & Rijal (2020)	Springwater quality	Sindhupalchok	Melamchi	18	–	–	–
16	Thapa *et al.* (2020)	Spring mapping, status, and water quality	Pyuthan, Arghakhachi	Jhimrukh watershed	102	1	94	Water consumption, climate change, anthropogenic stressors
17	Tiwari *et al.* (2020)	Springwater quality	Sindhupalchok	Helambu	57	–	–	–
18	Adhikari *et al.* (2021a)	Spring conservation, policy, and practice	Nepal	300 local governments	–	74% of local government	–	Mal-development practice, changing water use pattern, hill migrant influx in emergent towns and cities increasing water stress, limited knowledge of spring hydrogeology, aquifers and recharge zones, fluctuating weather anomalies and natural hazards

(*Continued.*)

Table 3 | Continued

S.No.	References	Major focus	District	Location	No. of studied springs	Dried-up springs (%)	Decreasing discharge (%)	Potential reason for declining discharge and drying up
19	Adhikari *et al.* (2021b)	Spring mapping and status	Surkhet, Dailekh, Achham, Kalikot, Doti, Kailai, Dadheldhura, Pyuthan, Arghakhanchi, Gulmi	Mid and far-western Nepal – 5 watersheds	4,222	1.6	70.0	–
20	Pradhan & Shrestha (2022)	Distribution modeling	Sankhuwasabha	Khandbari	–	–	–	–
21	This study	Spring mapping, status, and water quality	Kathmandu	Chandragiri	140	13.57	72.14	Over-extraction of groundwater, increased urbanization, decreasing precipitation

in the years to come (Joseph & Shrestha, 2022). A similar projection has been made by a report, according to which water availability in Nepal is anticipated to drop by 2030 and further decline by 2050 in the business-as-usual scenario, implying that water stress would continue to grow (Joseph & Shrestha, 2022).

3.4. Causes of spring degradation and their future implications

Springs are degrading at an alarming rate for several reasons. Out of the 21 studies on springs, nine have reported the reasons behind spring degradation in Nepal. The spring degradation is attributed to (i) climate change mainly declining rainfall (62% of studies), (ii) infrastructure development, such as roads, tunnels, and irrigation canals without environmental considerations (50% of studies), (iii) increased water consumption and extraction (50% of studies), (iv) natural disasters like an earthquake (37% of studies), (v) lack of systematic efforts in water conservation resulting in the vanishing of traditional ponds, lakes, and wallows (37% of studies), (vi) change in land use and land cover including concreting and piping of sources, deforestation (37% of studies), (vii) limited knowledge and awareness on springs hydrogeology (25% of studies), and (viii) an influx of migrants into towns and cities (25% of studies). Figure 5 illustrates the causes and nexus of spring degradation in Nepal.

Considering these reasons behind springs degradation in Nepal, it is likely that more springs will dry up in the future, leading to a severe water crisis in the country. The maximum temperature has already increased by 0.056 °C per year and the minimum temperature by 0.002 °C per year between 1971 and 2014 (DHM, 2017). The precipitation has been decreasing in mountains and hills, whereas the temperature trend increases northward with elevation and is highest (0.086 °C per year) in the high Himalayas. This observed trend has a direct link to the spring degradation in the mid-hills of Nepal as indicated by several studies (Poudel & Duex, 2017; Sharma *et al*., 2021). It is further projected that the mean temperature could increase by 0.9–1.1 °C in the medium-term period (2016–2045) and 1.3–1.8 °C in the long-term period (2036–2065) (MoFE, 2019). This means that climate change is likely to have a greater impact on the already degrading springs.

After the local election of 2017, development activities took a faster pace in Nepal. For instance, the local road network increased by 8,085 km between 2016 and 2020 (OPM, 2020). The development projects of different

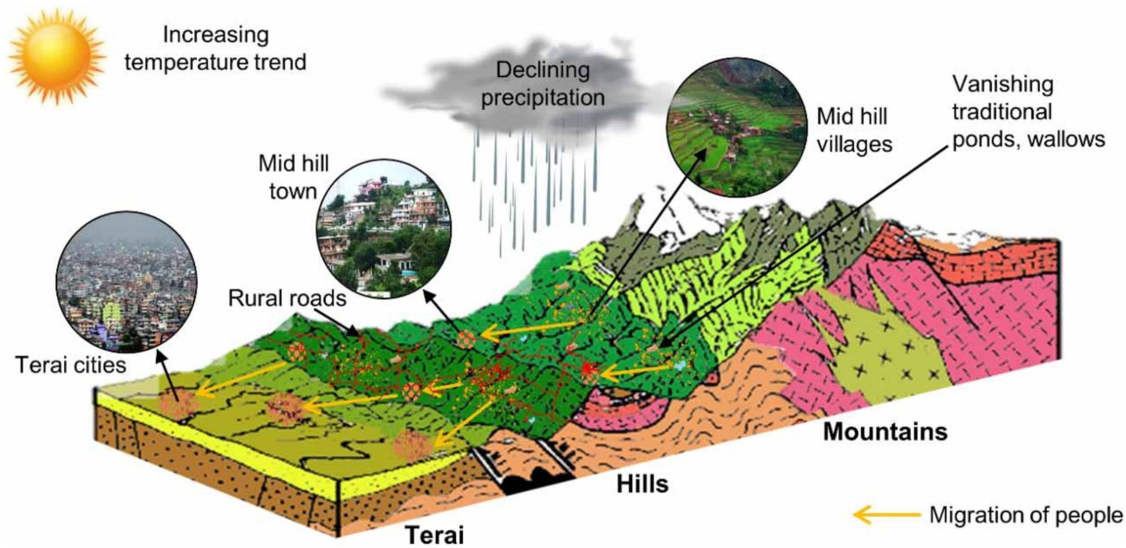


Fig. 5 | Causes and implications of spring degradation in Nepal (Modified after Raonline https://bit.ly/38fVom4).

scales should undergo environmental assessment as required by the Environment Protection Act of Nepal (EPA, 2019). However, most of the development activities undertaken by local governments were implemented without conducting environmental assessments and putting environment management plans and mitigation measures into consideration. As the consequences of such haphazard development, land-use change, disaster incidences, and environmental risk have increased over the past 5 years (Mcadoo *et al*., 2018). The impact of these consequences has been observed in the form of excessive resources degradation and loss including river bed extraction-induced flooding, rural roads-induced landslides (Sudmeier-Rieux *et al*., 2019), and drying up of springs induced by altered groundwater channels (Gurung *et al*., 2019a; Adhikari *et al*., 2021b).

According to the Central Bureau of Statistics (CBS, 2021), the urban population of Nepal has increased from 17.07% in 2011 to 66.08% in 2021. The water crisis in the mid-hills is one among many factors that have contributed to the high influx of people into towns and cities. In urban areas, a high population again means increased water demand, extractions, and consumption (Dhakal *et al*., 2021). This vicious cycle of population growth and water demand will deplete groundwater resources, increase the severity of the water crisis in the town and cities, and affects the health and sanitation of the urban dwellers.

3.5. Policy gaps and needs

In response to the degrading springs and water crisis, several initiatives have been made to cope with the situation. Some of the common solutions adopted by most of the municipalities facing severe water crises include (i) lifting surface and groundwater using electric pumps and redistributing to households (e.g. Myagdi, Kamal Bazar, Malika), (ii) diverting water from multiple spring sources through a pipe network to a common water tank (e.g. Surkhet, Sankhuwasabha), (iii) installing deep boring (e.g. Dharan), (iv) rainwater harvesting and (v) spring revival, protection and recharge programs including the construction of recharge ponds, stream ponds, fencing, plantation, and conservation awareness (e.g. Kavre, Dailekh, Dang).

Yet, such initiatives are very scattered, focused on individual springs, and not adequate to curb the current rate of spring degradation in Nepal. Comprehensive efforts can only be made through policy interventions. The issues of spring degradation and conservation are missing in the existing policies. The Water Resources Act 1992 allows for the formation of water user associations to oversee water projects, prioritizes water allocations for drinking water and irrigation, needs water abstraction licenses, lays out water quality protection standards, and specifies penalties for any infractions of the Act. The Water Resources Strategy 2002 defines the water sector's priorities, as well as the actions, indicators, and timelines that will be used to address them. For basin management, it adopts Integrated Water Resources Management (IWRM) concepts, proposes river basin planning units, and asks for IWRM basin management plans. The national water plan 2002–2027 defines the water sector's long-term investment portfolio and charges the Water and Energy Commission Secretariat with developing and coordinating water policy and sectoral development. District Water Resource Committees were established (DWRC) and restructured under IWRM principles, Sub-Basin Committees, and River Basin.

Similarly, the Local Government Operation Act 2017 has made local governments responsible for water resource management and mandated local governments for the planning, formulation, implementation, and regulation of water-related policies, laws, standards, and plans. The conservation of the local water resources including springs is the responsibility of local governments. The National Water Resource Policy (NWRP) 2020 unifies water policy and all water users, intending to resolve water-sharing problems among the province, district, and municipal administrations. New federal, provincial, and municipal entities are established to optimize water usage, development, management, and protection (MoEWRI, 2020).

All of the above-mentioned policies and legal instruments are more focused on planning and implementation at the river-basin level and the large water bodies such as rivers, and lakes. The policies have prioritized

Table 4 | Key considerations for policy and actions to curb spring degradation in Nepal.

Aspects	Considerations	Responsible agencies
Policy change	• Springshed approach for water resource conservation • Independent water management bodies at central and provincial levels • Effective horizontal and vertical coordination mechanism between three tiers of governments and stakeholders • Localize land use policy • Control migration from rural hills to towns and cities • Encourage investment in local water resources from the public and private sectors	Federal, provincial, and local governments
Coping with the crisis (water security)	• Use available water efficiently • Introduce new forms of water resources management at the watershed scale	Federal, provincial, local governments, private sector investment
Spring revival	• Integrate locally available knowledge and scientific information for spring revival • Rehabilitate traditional ponds, lakes, wallows, water-recharge ponds, construct conservation ponds, and check dams • Increase recharge-establish rainwater harvesting systems, piping rooftop water, and domestic wastewater into a recharge pit • Construction of recharge ponds, trenches, and bounds • Design and implement Janapratinidhi Pokhari Conservation Programme (one ward – seven pond campaign) • Plantation of selected trees species that hold moisture and preserve water source • Mobilize tole level organizations (TLOs) and encourage a participatory approach	Wards, local water user organizations, and local communities
Spring protection	• Strengthen environmental assessment and adopt mitigation measures for rural development projects • Impose restrictions on heavy equipment used in infrastructure development mainly around point sources of water • Prohibition on pesticide and chemical fertilizer use around springs • Develop the scheme and upstream–downstream mechanism for payment of ecosystem services • Improve water quality • Development without destruction	Wards, local water user organizations, and local communities
Research	• Mapping springs, aquifers, and recharge zones, assess groundwater availability and use	Universities, research institutions, governments, and donors/funding organizations

(*Continued.*)

Table 4 | Continued

Aspects	Considerations	Responsible agencies
	• Monitor discharge and water quality through a citizen science approach • Explore the nexus between the vegetation and springs discharge • Establish permanent plots/sites for long-term spring monitoring and research • Explore the scientific evidence of the causes of spring degradation • Identify scientifically proven methods for spring revival and sustainability	
Capacity building	• Strengthen the water management capacity of local governments • Increase technical expertise Pani Heralu (Water Watchers) • Community capacity building for water sustainability and climate change adaptation • Train young professionals as trainers in recharge pond construction	Federal, provincial, and local stakeholders
Knowledge sharing and awareness	• Spring conservation and revival in school and college curriculums • Document and promote traditional knowledge and best practices	Wards, local water user organizations, and local communities

interventions of the water resources that have multipurpose and multi-use potential. Unfortunately, they have ignored the issues of streams and springs observed at the springshed level, which are crucial for the livelihood and economy of the communities. The basin-level planning cannot address the local water issues such as spring degradation.

Some issues of springs have been incorporated into the NWRP. The NWRP aims to identify springs and hot springs throughout the country and make their appropriate uses, protect the identified springs, and prevent and control haphazard solid waste and effluent disposal around water resources including springs. Yet again, the policy to address spring degradation and revival is missing in the NWRP as well. On the one hand, springs are degrading at an alarming rate which has affected both urban and rural livelihoods, and on the other hand, the updated policy and legal instruments are dilute in terms of spring revival and protection. The policies that are intended to operate at the basin and watershed level may not be effective at the springshed level. Therefore, a dedicated policy is necessary for comprehensive but differentiated actions to be operated at the springshed level to curb the spring degradation and water crisis in Nepal. Every published study related to spring status in Nepal has also emphasized the need for a dedicated policy for spring conservation and revival (Sharma *et al.*, 2016; Chapagain *et al.*, 2019; Adhikari *et al.* 2021b). Some of the aspects that need to be considered while formulating the dedicated policy of spring conservation are given in Table 4.

After the promulgation of the Constitution of Nepal, the country was federated into seven provinces and 753 local governments, with a total of 761 governments at three levels. The lowest administrative units of Nepal are wards, which are also the grassroots-level policy-program implementation institutions. A ward contains several springshed, however, a watershed is shared by at least two wards or even municipalities as most of the administrative divisions in Nepal are separated by rivers and streams. Therefore, for the conservation and revival of water resources and implementation of the water resources protection programs, the ward-level-springshed approach could be the most appropriate level considering the current administrative structure of Nepal.

4. CONCLUSIONS

This study shows that the degradation of the spring is occurring both in rural and urban areas. Water stress in the mid-hills and mountains is more severe than it is considered to be. This situation has already affected the livelihood of the people and economy and if this trend continues, migration induced by the environmental crisis will rise in coming years, putting more pressure on the carrying capacity of urban centers. Current efforts are not adequate and effective to solve water-related problems and more comprehensive efforts are required. This can only be achieved through the paradigm policy shift. The water policies of Nepal are more concentrated on surface water resources that have the potential for developing multipurpose projects. Therefore, a new policy should be implemented that can bridge the basin and watershed level planning to the springshed level, adopt a bottom-up approach, strengthen local water stakeholders for improved water governance, put systematic efforts into water conservation, and realign the current trend of haphazard development for revitalizing water resources, sustaining water availability, increasing productivity, and generating prosperity.

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DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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