

# A Comprehensive Review of Springshed Mapping and Recharge Interventions: Insights for Mountain and Hill Areas

Raushan Aditya Raj<sup>1</sup>, Manjeet Singh<sup>2</sup>, Balram Sharma<sup>3</sup>,  
Roshan Lal Meena<sup>4</sup>

<sup>1,2,3</sup>Department of Soil and Water Conservation Engineering, CTAE, MPUAT, Udaipur, Rajasthan, India

<sup>4</sup>ICAR-NBSS&LUP, Regional Centre, Udaipur, Rajasthan, India

## Abstract

Springs serve as a critical freshwater source for millions of people in mountainous, arid, and karst regions worldwide, with 50-80% of rural Himalayan communities depending on spring water for daily needs. Over recent decades, widespread spring discharge decline has been documented across diverse settings. This review synthesizes current understanding of springshed delineation and management across four domains. First, geomorphological characterization is examined through spring typology (gravity, contact, fracture, and karst springs), topographic and hypsometric analysis, drainage pattern delineation, and land cover influence on recharge. Second, discharge measurement techniques are reviewed, ranging from manual volumetric methods to automated high-frequency monitoring, alongside water quality characterization using physicochemical analysis, hydrochemical facies classification, and Water Quality Index computation. Third, vulnerability assessment and protection zoning frameworks, including integrated hydraulic-time and contamination-vulnerability approaches, are evaluated for their role in safeguarding recharge areas. Fourth, the effectiveness of recharge augmentation structures, including check dams, contour bunds, gabion structures, and percolation tanks, is synthesized using quantitative evidence from intervention studies, which documented discharge increases ranging from 6% to over 100%. The review highlights those springsheds, unlike surface watersheds, are governed by subsurface hydrogeological boundaries that often diverge from topographic divides, necessitating integrated, site-specific, and adaptive management approaches to ensure long-term spring sustainability under combined climatic and anthropogenic pressures.

**Keywords:** Springshed delineation; spring discharge; groundwater recharge; water quality assessment; sustainable spring management.

## 1. Introduction

Springs are natural discharge points where groundwater emerges at the land surface, serving as vital water sources for domestic consumption, agriculture, and ecosystem maintenance, particularly in mountainous and arid regions (Singh Thapa Chitra, 2023). Globally, springs support the livelihoods of millions of people, with an estimated 50-80% of rural Himalayan communities depending on spring water for their daily needs (Kumar & Paramanik, 2020; Sharma et al., 2019). However, over the past few

decades, widespread spring discharge decline has been documented across diverse geographical settings, from the Hindu Kush Himalayas to karst terrains in the Mediterranean and fractured volcanic aquifers in Central America (Javadi et al., 2019; Supangat et al., 2022; Valle et al., 2021).

The causes of spring drying are multifaceted and include climate change impacts (altered precipitation patterns, reduced snowpack, increased evapotranspiration), anthropogenic activities (deforestation, land-use conversion, unplanned infrastructure development), and inadequate groundwater management (Bhattarai et al., 2023; Dhakal & Karki, 2023; Keesari et al., 2025). In the Garhwal Himalayas, for instance, studies have reported that 50-70% of perennial springs have either dried up or experienced significant discharge reduction over the last two decades (Kumar & Paramanik, 2020). Similarly, in Kashmir Valley, approximately 6.2% of surveyed springs were found to have water quality unsuitable for drinking, while many others showed declining discharge trends (Bhat et al., 2022).

The concept of a "springshed" analogous to a watershed but focused on the groundwater recharge area contributing to a specific spring has emerged as a critical framework for understanding and managing spring systems (Verma & Jamwal, 2022). Unlike surface watersheds, springsheds are defined by subsurface hydrogeological boundaries that may not coincide with topographic divides, particularly in karst and fractured rock aquifers (Cameron, 2025; Eslamian & Eslamian, 2024). Accurate springshed delineation is therefore essential for identifying recharge zones, assessing vulnerability to contamination, and designing effective conservation interventions (Kukreti et al., 2026).

Recent advances in geospatial technologies, isotope hydrology, and hydrogeological modeling have significantly enhanced our ability to delineate springsheds and characterize spring systems (Lyu et al., 2024) (Petitta et al., 2022). Geographic Information Systems (GIS) combined with multi-criteria decision analysis (MCDA) and analytical hierarchy process (AHP) enable integration of diverse spatial datasets including geology, topography, land use, soil characteristics, and climate variables to identify spring potential zones and recharge areas (Aurilia et al., 2021; Ranjan et al., 2023). High-frequency discharge monitoring coupled with recession analysis and flow-duration curves quantifies storage dynamics and intervention effectiveness (Kumar & Paramanik, 2020).

## 2. Geomorphological Characteristics of Springshed Areas

Understanding the geomorphological characteristics of springshed areas is fundamental to effective spring management and conservation. The physical and structural landscape elements control where and how springs recharge and discharge, thereby determining their vulnerability, sustainability, and response to interventions. This section synthesizes findings on spring classification, lithological controls, topographic influences, recharge altitude determination, drainage patterns, and land cover effects.

### 2.1 Spring Classification and Typology

Spring classification based on hydrogeological mechanisms provides critical insights into flow behavior, storage capacity, and vulnerability to environmental changes. The primary spring types identified in the literature include gravity springs, contact springs, fracture springs, and karst (solution tubular) springs (Barman et al., 2022). Gravity springs emerge where the water table intersects the land surface due to topographic relief. These springs are common in mountainous terrains and are highly sensitive to seasonal precipitation variations and land-use changes in their recharge areas (ICIMOD,

2016). Contact springs occur at lithological boundaries where permeable formations overlies impermeable layers, forcing groundwater to discharge at the contact interface (Barman et al., 2022). These springs are particularly prevalent in sedimentary and metamorphic terrains of the Himalayas (Negi & Pant, 2025).

Fracture springs are controlled by structural features such as faults, joints, and fracture networks that create preferential flow pathways in otherwise low-permeability rocks (Sanz et al., 2020). In fractured volcanic media, such as those studied in Central Mexico, fracture connectivity and orientation significantly influence springsheds extent and recharge dynamics (Valle et al., 2021). Karst springs develop in carbonate rocks through dissolution processes that create conduit networks, caves, and solution channels (Hunt et al., 2019).

## 2.2 Topographic and Hypsometric Analysis

Topography exerts strong control on groundwater flow direction, recharge potential, and spring emergence locations. Elevation, slope gradients, aspect, and valley geometry are routinely analyzed to locate recharge altitudes and likely flow convergence zones (Li et al., 2004; Ranjan et al., 2023). In mountainous regions, springs typically emerge at mid-to-lower elevations, while recharge occurs at higher elevations where precipitation is greater and evapotranspiration is lower (Zhang, 2022). In Sikkim Himalayas, more than 80% of springs were distributed between 600 and 1,800 meters above sea level (m ASL) on slopes of 10-40 degrees, with most springs emerging in subtropical wet hill forest zones between 1,400 and 1,800 m ASL (Dhakal & Karki, 2023). This altitudinal distribution reflects the interplay between precipitation gradients, vegetation cover, and lithological controls.

Hypsometric analysis the distribution of land area with elevation is used to estimate the proportion of a springsheds at different altitudes, which in turn influences recharge rates and seasonal discharge patterns (Wigati et al., 2022). Springs with large high-elevation recharge areas tend to have more stable baseflow and greater resilience to drought, as demonstrated in studies of carbonate aquifers in central Italy where snowmelt from high-elevation subbasins was identified as a primary recharge source (Petitta et al., 2022).

## 2.3 Drainage Patterns and Springsheds Extent

Delineation of springsheds boundaries and drainage patterns is a fundamental step in spring management, yet it presents significant challenges due to the subsurface nature of groundwater flow. Unlike surface watersheds, which are defined by topographic divides, springsheds are controlled by hydrogeological boundaries that may diverge substantially from surface topography, particularly in karst and fractured rock aquifers (Cameron, 2025; Eslamian & Eslamian, 2024; Tewari & Tewari, 2023). In Central Java, springs exhibited radial drainage patterns, with a delineated springsheds area of 3,347.7 hectares, over 70% of which was covered by teak forest plantations (Supangat et al., 2022). The radial pattern suggested relatively localized recharge, allowing for focused conservation efforts within a defined area. In contrast, karst springs in Florida exhibited overlapping and interconnected springsheds boundaries, with core areas remaining relatively stable but peripheral boundaries showing substantial temporal variability in response to pumping and seasonal recharge fluctuations (Cameron, 2025).

GIS-based springsheds delineation typically employs topographic analysis, hydrogeological mapping, and, where available, groundwater flow modeling (Karami et al., 2016). In the Lesser

Himalayas, a GIS-based multi-criteria decision approach integrated geology, geomorphology, land use, slope, drainage density, and lineament density to map spring emergence zones and potential recharge areas. The resulting springshed maps provided a robust and transferable framework for sustainable management planning (Kukreti et al., 2026). Advanced delineation methods combine analytical models with vulnerability indices to define protection zones more accurately.

### 2.4 Land Cover and Vegetation Influence

Land cover and vegetation within springshed areas exert significant influence on infiltration rates, surface runoff, evapotranspiration, and ultimately spring discharge (Bagheri et al., 2022). Forest cover, in particular, plays a complex and sometimes contradictory role in spring hydrology, enhancing infiltration through root channels and organic matter accumulation while simultaneously increasing evapotranspiration (Vira et al., 2018). In the Central Java springshed study, over 70% of the 3,347.7 ha springshed was covered by teak forest plantations, which were considered beneficial for maintaining infiltration and reducing surface runoff (Supangat et al., 2022). Similarly, in Sikkim, most springs emerged from zones of subtropical wet hill forest between 1,400 and 1,800 m ASL, suggesting that forest cover at these elevations supports spring recharge (Dhakal & Karki, 2023). Agricultural land use within springsheds presents both opportunities and risks. While agricultural fields can provide infiltration surfaces if managed appropriately, intensive agriculture with heavy irrigation, pesticide application, and soil compaction can reduce recharge and increase contamination risk (Schröder, 2018). In Sikkim, more than 50% of spring points were located in agricultural fields, highlighting the need for integrated land-use planning that balances agricultural productivity with spring conservation (Dhakal & Karki, 2023). Deforestation and land-use conversion are frequently cited as major drivers of spring decline (Nugroho et al., 2019). In Nepal, problems related to spring conservation included drying up and displacement of springs by floods, landslides, and road construction, as well as pollution through agricultural runoff, livestock grazing, and contamination by pesticides and chemical fertilizers.

**Table 1: Changes in Spring Discharge After Recharge Measures**

Location	Context	Discharge Increases	Source
Nepal	Water augmentation structures in identified recharge areas	<ul style="list-style-type: none"> <li>▪ Winter spring discharge increased by 32.38-67.99%</li> <li>▪ Pre-monsoon discharge increased by 28.39-55.82%</li> <li>▪ A previously dried well revived to 9.3 lpm (winter) and 6.36 lpm (pre-monsoon)</li> </ul>	(Singh Thapa Chitra, 2023)
Mathamali Spring, Garhwal Himalaya	Springshed interventions implemented in early April 2017	<ul style="list-style-type: none"> <li>▪ Average flow increased by 2.6 times (from 16.9 lpm).</li> <li>▪ Minimum flow increased by 5 times (from 2.3 lpm).</li> <li>▪ Maximum flow increased by 1.8 times.</li> <li>▪ Storage duration increased by 16%.</li> </ul>	(Kumar & Paramanik, 2020)

Sikkim (Dhara Vikas Initiative)	Pilot interventions using the mountain aquifer approach	<p>Lean season discharge increases:</p> <ul style="list-style-type: none"> <li>▪ &gt;80% for Kharkhare Kholsha (Deythang landscape)</li> <li>▪ 70% for Aitabarey and Nunthaley Dhara (Deythang landscape)</li> <li>▪ 21-107% across five springs in the Tendong landscape</li> <li>▪ 10-15% in the Sadam landscape</li> </ul>	(Dhakal & Karki, 2023)
---------------------------------	---	---	------------------------

## 5. Conclusion

This review synthesized current understanding of springshed delineation and management across geomorphological characterization, discharge assessment, water quality evaluation, and recharge augmentation, drawing on evidence from the Himalayas, Central Java, Florida, Iran, and Central America. Spring systems globally face accelerating pressure from climate change, deforestation, agricultural intensification, and groundwater overextraction, with 50-70 percent of perennial springs in the Garhwal Himalayas already lost or significantly diminished, underscoring the urgency of systematic scientific intervention. Geomorphological analysis confirmed that spring type classification, slope gradient, lithological controls, and vegetative cover collectively govern spring occurrence and discharge behavior. These parameters must form the basis of any springshed management framework, since slope-specific structure selection and accurate springshed delineation are prerequisites for effective recharge augmentation. Discharge monitoring and Water Quality Index computation were identified as the essential baseline tools for spring resource assessment, enabling detection of seasonal vulnerability, intervention effectiveness, and water safety for dependent communities. Evidence on recharge augmentation was unambiguous: targeted interventions produced discharge increases of 6 to over 100 percent across diverse settings, with the Mathamali Spring study and Sikkim's Dhara Vikas initiative demonstrating that spring revival is empirically achievable, scalable, and cost-effective. The critical methodological insight of the review is that springsheds are governed by subsurface hydrogeological boundaries that frequently diverge from topographic divides, making integrated GIS, geological, and hydrogeological analysis essential for accurate delineation and preventing mis-targeted interventions. Systematic, preventive, science-based springshed management integrating inventory, monitoring, protection zoning, and community participation represents the most viable pathway to securing the freshwater future of the millions of people globally who depend on springs as their primary water source.

## References

1. Aurilia, M. F., Santoso, D. H., & Sungkowo, A. (2021). Determination of Zoning Recharge Area and Spring Conservation in the Upstream Sub-Basin of the Jali River, Gebang District, Purworejo Regency, Central Java Province. *Jurnal Presipitasi : Media Komunikasi Dan Pengembangan Teknik Lingkungan*, 18(1), 10–20. <https://doi.org/10.14710/presipitasi.v18i1.10-20>
2. Bagheri, R., Mirhasani, G., Jafari, H., & Mozafari, M. (2022). Quantify karstic aquifer potential

- recharge zones by integrated hydrogeology and GIS approaches, Northern Iran. *Geopersia*, 12(1), 23–37. <https://doi.org/10.22059/GEOPE.2021.323407.648616>
3. Barman, P., Ghosh, J., & Deb, S. (2022). Study of water quality, socio-economic status and policy intervention in spring ecosystems of Tripura, Northeast India. *Discover Water*, 2(1). <https://doi.org/10.1007/s43832-022-00015-9>
  4. Bhat, S. U., Dar, S. A., & Hamid, A. (2022). A critical appraisal of the status and hydrogeochemical characteristics of freshwater springs in Kashmir Valley. *Scientific Reports*, 12(1). <https://doi.org/10.1038/s41598-022-09906-2>
  5. Bhattarai, C., Tiwari, S., Pokharel, G. S., Sharma, B., Gyawali, D., Gautam, D., Pokharel, A., Paudel, B., & Prajapati, T. (2023). Connecting innovation and source conservation for meeting water needs. *Journal of Nepal Geological Society*, 65, 89–98. <https://doi.org/10.3126/jngs.v65i01.57754>
  6. Cameron, C. (2025). Modeling groundwater contributing areas to Florida springs: spatiotemporal variability and pumping effects on springshed boundaries. *The Stacks*. <https://doi.org/10.60102/stacks-25009>
  7. Dhakal, S., & Karki, S. B. (2023). Dhara Vikas: A climate change initiative to revive drying springs in Sikkim Himalayas. *Advances in Geographical Research*, 66–100. [https://www.researchgate.net/profile/Namdev-Telore-2/publication/378040318\\_ADVANCES\\_IN\\_GEOGRAPHICAL\\_RESEARCH/links/65c46a6034bbff5ba7f55593/ADVANCES-IN-GEOGRAPHICAL-RESEARCH.pdf#page=78](https://www.researchgate.net/profile/Namdev-Telore-2/publication/378040318_ADVANCES_IN_GEOGRAPHICAL_RESEARCH/links/65c46a6034bbff5ba7f55593/ADVANCES-IN-GEOGRAPHICAL-RESEARCH.pdf#page=78)
  8. Eslamian, S., & Eslamian, F. (2024). *Hydrosystem Restoration Handbook: Streamflow Recharge and Lake Rehabilitation: Volume 1*. *Hydrosystem Restoration Handbook: Streamflow Recharge and Lake Rehabilitation: Volume 1*, 1, 1–302. <https://doi.org/10.1016/C2023-0-01443-1>
  9. Hunt, B. B., Smith, B. A., & Hauwert, N. M. (2019). Barton Springs segment of the Edwards (Balcones Fault Zone) Aquifer, central Texas. *Memoir of the Geological Society of America*, 215, 75–99. [https://doi.org/10.1130/2019.1215\(07\)](https://doi.org/10.1130/2019.1215(07))
  10. ICIMOD. (2016). *Community Training Manual: Springshed Management in the Hindu Kush Himalayas - Aspects of Groundwater and Hydrogeology*. Training Manual. <http://lib.icimod.org/record/32181>
  11. Javadi, S., Moghaddam, H. K., & Roozbahani, R. (2019). Determining springs protection areas by combining an analytical model and vulnerability index. *Catena*, 182. <https://doi.org/10.1016/j.catena.2019.104167>
  12. Karami, G. H., Bagheri, R., & Rahimi, F. (2016). Determining the groundwater potential recharge zone and karst springs catchment area: Saldoran region, western Iran. *Hydrogeology Journal*, 24(8), 1981–1992. <https://doi.org/10.1007/s10040-016-1458-z>
  13. Keesari, T., Pant, D., Mohokar, H., & Khatti, V. (2025). Revival of drying springs in mountainous regions of the Himalayas - Inferences from an isotope hydrochemical study. *Water Resources Management in Mountain Regions*, 135–159. <https://doi.org/10.1002/9781394249619.ch8>
  14. Kukreti, A., Rawat, S. S., Malik, D. S., Dar, T. A., & Dass, B. (2026). Mapping Spring Emergence Zones in the Lesser Himalaya, India Using a GIS-Based Multi-Criteria Decision Approach. *Earth Systems and Environment*. <https://doi.org/10.1007/s41748-026-01154-y>
  15. Kumar, V., & Paramanik, S. (2020). Application of high-frequency spring discharge data: A case

- study of Mathamali spring rejuvenation in the Garhwal Himalaya. *Water Science and Technology: Water Supply*, 20(8), 3380–3392. <https://doi.org/10.2166/ws.2020.223>
16. Li, Y., Yeh, G. T. G., & Wanielista, M. P. (2004). Modeling Wekiva Springshed, Florida with WASH123D. *Developments in Water Science*, 55(PART 2), 1441–1452. [https://doi.org/10.1016/S0167-5648\(04\)80156-4](https://doi.org/10.1016/S0167-5648(04)80156-4)
17. Lyu, K., Zhang, Q., Cui, Y., Zhang, Y., Zhou, Y., Lyu, L., Dong, Y., & Shao, J. (2024). Optimizing Recharge Area Delineation for Small- to Medium-Sized Groundwater Systems through Coupling Methods and Numerical Modeling: A Case Study of Linfen City, China. *Sustainability (Switzerland)*, 16(4). <https://doi.org/10.3390/su16041465>
18. Negi, G. C. S., & Pant, D. (2025). Springs of Uttarakhand Mountains: A State of Knowledge Review with Focus on Rejuvenation of Drying Springs. *International Journal of Ecology and Environmental Sciences*. <https://ojs.nieindia.org/index.php/ijeec/article/view/754>
19. Nugroho, M., Soemarno, S., Riniwati, H., & Afandhi, A. (2019). Community Empowerment Model for Forest Revegetation and Preservation the Area Around the Springs: Arjuna Mount Case Study in East Java, Indonesia. August, 1–35. <https://www.preprints.org/manuscript/201908.0313>
20. Petitta, M., Banzato, F., Lorenzi, V., Matani, E., & Sbarbati, C. (2022). Determining recharge distribution in fractured carbonate aquifers in central Italy using environmental isotopes: snowpack cover as an indicator for future availability of groundwater resources. *Hydrogeology Journal*, 30(5), 1619–1636. <https://doi.org/10.1007/s10040-022-02501-9>
21. Ranjan, P., Pandey, P. K., & Pandey, V. (2023). Delineation of Spring Potential Zones using Geospatial Techniques: Arunachal Pradesh, India. *Current World Environment*, 18(1), 87–101. <https://doi.org/10.12944/cwe.18.1.8>
22. Sanz, E., Rosas, P., Menéndez-Pidal, I., & de Ojeda, J. S. (2020). Modeling and prefeasibility management, and conservation strategies for fuentetoba springs, (Spain). *Sustainability (Switzerland)*, 12(23), 1–14. <https://doi.org/10.3390/su122310131>
23. Schröder, H. C. (2018). Large-scale High Head Pico Hydropower Potential Assessment.
24. Sharma, D., Khandekar, N., & Sachdeva, K. (2019). Addressing water-related shocks and coping decision through enhanced community participation: Case studies from Ganga basin, Uttarakhand, India. *Water Policy*, 21(5), 999–1016. <https://doi.org/10.2166/wp.2019.026>
25. Singh Thapa Chitra, R. (2023). The Implication of Hydrogeological Mapping and Recharge Structures to Revive Drying Springs in Hilly Region of Nepal. *International Journal of Science and Research (IJSR)*, 12(5), 2026–2032. <https://doi.org/10.21275/sr23522075701>
26. Supangat, A. B., Purwanto, Hendrayana, H., & Riyanto, H. D. (2022). Springshed protection planning for combating drought in Grobogan District, Central Java. *IOP Conference Series: Earth and Environmental Science*, 1016(1). <https://doi.org/10.1088/1755-1315/1016/1/012022>
27. Tewari, B., & Tewari, A. (2023). Spring shed development by employing traditional practices for spring revival and reducing women drudgery in Kumaun Himalayan Region. *Ecology, Environment and Conservation*, 29, 120–127. <https://doi.org/10.53550/eec.2023.v29i03s.025>
28. Valle, S. L., Castillo, J. L. E., Alberich, M. V. E., Albores, M. A. G., Tavares, J. P., & Esquivel, J. M. (2021). Delineation of protection zones for springs in fractured volcanic media considering land use and climate change scenarios in central Mexico region. *Environmental Earth Sciences*, 80(9). <https://doi.org/10.1007/s12665-021-09662-y>

29. Verma, R., & Jamwal, P. (2022). Sustenance of Himalayan springs in an emerging water crisis. *Environmental Monitoring and Assessment*, 194(2). <https://doi.org/10.1007/s10661-021-09731-6>
30. Vira, B., Ellison, D., McNulty, S. G., Archer, E., Bishop, K., Claassen, M., Gush, M., Gyawali, D., Martin-ortega, J., Mukherji, A., Murdiyarsa, D., Pol, P. O., Sullivan, C. A., & Noordwijk, M. Van. (2018). Management Options for Dealing with Changing Forest-Water Relations. *Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities*, 121–140. [https://researchspace.csir.co.za/dspace/bitstream/handle/10204/10344/Vira\\_21103\\_2018.pdf?sequence=1](https://researchspace.csir.co.za/dspace/bitstream/handle/10204/10344/Vira_21103_2018.pdf?sequence=1)
31. Wigati, R., Mina, E., Fathonah, W., Kusuma, R. I., Ujianto, R., Soelarso, S., Priyambodho, B. A., Soedarsono, S., & Mulyono, H. (2022). Konservasi vegetatif kendalikan aliran permukaan daerah resapan mata air. *Civil Engineering for Community Development (CECD)*, 1(1), 51. <https://doi.org/10.36055/cecd.v1i1.17244>
32. Zhang, A. (2022). Delineation of spring capture zones in southern Great Basin, USA based on modeling results and geochemical data. *Water Science and Engineering*, 15(3), 189–199. <https://doi.org/10.1016/j.wse.2021.12.009>