सत्यमेव जयते

Resource book

for

Springshed Management in the Mountainous Regions of India

Department of Water Resources, River Development & Ganga Rejuvenation

Ministry of Jal Shakti, Government of India

Resource Book

SPRINGSHED MANAGEMENT IN THE MOUNTAINOUS REGIONS OF INDIA

Pinakot village spring, Sult block, Almora

Department of Water Resources, River Development and Ganga Rejuvenation

Ministry of Jal Shakti, Government of India

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Springs captured from the various locations of Udhampur, Jammu & Kashmir; Chamba, Himachal Pradesh; and Tehri Garhwal, Uttarakhand.

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आज़ादी का अमृत महोत्सव

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास
और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

FOREWORD

Springs, the visible manifestation of groundwater, are vital water sources for millions in India's mountainous regions, supporting around 200 million people, particularly in the Indian Himalayas, Western Ghats, Eastern Ghats, and Central India. They offer pure water economically and sustain river flow, biodiversity, and agricultural and industrial growth.

Climate change, deforestation, and unsustainable development practices are exerting immense pressure on these springs. Between 1961 and 2011, the Himalayan population grew by 250%, three times the world average growth rate. This rapid growth has led to accelerated urbanisation, resulting in damage to recharge zones and degradation of water quality in the springs. Ever-increasing stress due to natural and anthropogenic reasons on these vital water sources has led to the drying or reduced flow. Neglect over recent decades has worsened water scarcity, aggravated by the lack of systematic data on springs, hindering policy integration despite their critical importance.

Ensuring the long-term survival of mountain ecosystems and the well-being of millions, requires sustainable development practices and ecosystem protection. Springshed management, crucial for spring preservation and rejuvenation, requires scientific studies aligning with local wisdom. The Honourable Prime Minister of India emphasised the need to expedite springshed management during the 'All India Annual State Ministers Conference on Water @2047' in January 2023. Strengthening institutional capabilities for systematic, scientific interventions is now imperative to address spring ecosystem challenges effectively.

Recognising the critical role of springs in water and ecological security, the Department of Water Resources, River Development & Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti, the Government of India has prioritised their protection and rejuvenation. To this end, a Steering Committee on 'Springshed Mapping of the Indian Himalayan Region (IHR) Including Mountainous Regions of the Country and Springshed-based Watershed Management Plan' was established. The objective of the committee is to address key challenges related to conservation and sustainable management of springshed management across the country.The committee, supported by technical expertise, initiated the First Springs Census to expedite nationwide springshed management. Responding to the need for comprehensive guidance, the committee, led by Shri Subodh Yadav, Joint Secretary, crafted the 'Resource Book and SoPs for Springshed Management in the Mountainous Regions of India,' featuring insights from domain experts and implementing agencies for practical utility.

I am confident that stakeholders in springshed management will find great value in these scientific documents, aiding our collective endeavor to enhance spring civilisations in mountainous regions. Let's unite under the principle of 'Vasudhaiva Kutumbakam' to conserve these water sources and nurture a prosperous, water-abundant world.

(Debashree Mukherjee)

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आज़ादी का अमृत महोत्सव

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PREFACE

For generations, mountain communities have relied on springs as their primary water source, evident from the clustering of villages around these natural fountains. These springs have not only sustained life but also held profound cultural and social significance, embodying traditional methods of resource conservation. These springs have remained steadfast in ensuring water security for the inhabitants of India's mountainous regions. Yet, despite their indispensable role, they've been largely overlooked. The burgeoning population coupled with climate change has accelerated the depletion of these vital water reservoirs, posing a grave threat to the communities dependent on them. The urgency to rejuvenate these springs cannot be overstated. It demands a strategic approach that integrates scientific insights with indigenous knowledge, acknowledging the intricate dynamics of these fragile ecosystems.

Over the past decade, several initiatives have been undertaken by both governmental and non-governmental organizations to address spring-shed development and management.

However, a lack of standardisation in data collection and management methodologies persists among these diverse entities. This inconsistency poses a significant obstacle to scaling up spring-shed management efforts nationwide. It is imperative to establish a standardized framework for spring-shed management, synthesising the wealth of local wisdom with modern scientific practices. Only through cohesive collaboration and unified action can we effectively safeguard these invaluable water sources for generations to come.

To accelerate spring-shed management efforts nationwide, the Department of Water Resources, River Development & Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti, Government of India, established a Steering Committee focused on Spring-shed Mapping of IHR Including Mountainous Regions of the Country and Spring-shed Based Watershed Management Plan.' This committee, comprising officials from state and central agencies, NGOs, and domain experts, aims to standardise methodologies, initiate mapping, and enhance capacity for spring-shed management. Additionally, it seeks to address challenges faced by implementing agencies by developing a comprehensive "resource book" on the subject.

The resource book is the positive outcome of brainstorming and workshops spearheaded by the steering committee. The book contains 11 chapters covering various essential aspects of spring-shed management like database assessment, standard definitions and classifications, mapping methodologies, discharge measurement techniques, holistic management strategies, water quality protocols, environmental isotopes' use, tailored guidelines, discharge indexes, project impacts, and capacity building, addressing challenges, skills gaps, and effective mechanisms through dedicated chapters.

This Resource Book has led to the SoP formulation for spring-shed management. Both of these documents are expected to enhance ongoing efforts and motivate stakeholders to promote the sustainable development of these vital resources. It will also serve as a valuable resource for incorporating future contributions from implementing agencies. I believe it will usher in a new era of holistic spring-shed management, ensuring the preservation and optimal utilisation of this precious resource.

(Subodh Yadav, IAS)
Joint Secretary
Chairman, Steering Committee for Spring-shed Mapping of IHR including Mountainous Regions of the Country

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List of Abbreviations

ACWADAM	Advanced Centre for Water Resources Development and Management
AR	Aquifer Recharge
AWS	Automatic Weather Station
CCT	Continuous Contour Trenches
CFS	Cubic Feet Per Second
CHIRAG	Central Himalayan Rural Action Group
CN	Curve Number
CRM	Certified Reference Material
CRP	Community Resource Persons
CRS	Corporate Social Responsibility
DoLR	Department of Land Resources
DoWR,RD&GR	Department of Water Resources, River Development & Ganga Rejuvenation
DVR	Discharge Variability Ratio
EDC	Electronic Data Collection
GBPINHE	GB Pant National Institute of Himalayan Environment
GPM	Gallons Per Minute
GSI	Geological Survey of India
HKHR	Hindu Kush Himalayan region
IBM	Incentive-Based Mechanism
ICPMS	Inductively Coupled Plasma Mass Spectrometry

IHR	Indian Himalayan Region
IMSD	Integrated Mission for Sustainable Development
IWMP	Integrated Watershed Management Programme
LMWL	Local Meteoric Water Line
LPM	Liters Per Minute
LULC	Land Use Land Cover
MBDA	Meghalaya Basin Development Authority
MGD	Million Gallons Per Day
NGO	Non-government organization
NHP	National Hydrology Project
NIH	National Institute of Hydrology
O&M	Operation and Maintenance
ORGs	Ordinary Raingauges
PDC	Paper-based Data Collection
PSI	People Science Institute
QA	Quality Assurance
QC	Quality Control
RMDD	Rural Management & Development Department
RSC	Residual Sodium Carbonate
RWH	Rooftop Rainwater Harvesting
SAR	Sodium Adsorption Ratio
SCT	Staggered Contour Trenches
SDGs	Sustainable Development Goals
SOI	Survey of India
SOP	Stranded Operating Procedure
SSM	Springshed Management
TDS	Total Dissolved Solids
ToT	Training of Trainers

Chapter 1

Introduction

1.1 Background

Springs, the visible manifestation of groundwater on the earth's surface, serve as the primary source of water for millions of inhabitants in the mountain ranges across India. A gross estimate of nearly 200 million Indians depends on spring water mainly in the Indian Himalayan Region (IHR), Western Ghats (Sahyadri mountain range, traversing the states of Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu), Eastern Ghats (Northern Odisha, Andhra Pradesh, and Tamilnadu) and Central India (Satpura and Vindhyas mountains). Water resources are a vital aspect of the mountainous ecosystem, which is the source of several major rivers that are crucial for the agriculture and industry of the nation. The mountainous ecosystem also contains several wetlands, lakes, and springs that are essential for the survival of aquatic species and the region's biodiversity. Water resources, including springs, are indispensable for sustaining life in the IHR and other mountainous regions of India. The IHR is an ecosystem that spans over 5,37,435 km^2 (comprising about 16.3% of India's total geographical area) and is home to a diverse range of flora and fauna (Negi & Dhyani, 2012). The region is characterized by high altitude, steep slopes, and extreme climatic conditions, and is known for its glaciers, snow-capped mountains, and dense forests. However, climate change, deforestation, and unsustainable development practices are putting immense pressure on the IHR's water resources (Tambe et al., 2012). It is imperative to adopt sustainable development practices and protect the mountainous ecosystem for its long-term survival and the well-being of the million's dependent on it. However, over the past few decades numerous springs have either dried-up or became seasonal due to unfavourable anthropogenic activities, and the adverse effects of rising air temperature and erratic rainfall patterns.

Therefore, Springshed Management (SSM), incorporating scientific studies and local knowledge, has become an urgent need to safeguard and rejuvenate these springs.

1.2 Importance of springs and government's initiatives

Springs are a common occurrence in the mountainous regions of India, including the IHR. Spring water sources are typically smaller in size compared to other water bodies such as rivers, lakes, and reservoirs. They form when water from underground aquifers emerges at the surface due to geological and topographical factors (Dar et al., 2022; Kresic & Stevanovic, 2009; Kulkarni et al., 2015). Indian mountains are home to several hot and cold springs that are known for their therapeutic properties and are popular tourist destinations. Despite their small size, springs play a crucial role in sustaining life in various regions, particularly in mountainous areas where they might serve as the primary water source for local communities. Moreover, these springs contribute to the unique ecosystems by supporting a diverse range of plant and animal species adapted to these habitats. In mountainous regions, terraced fields rely on springs for irrigation, underscoring their significance in agriculture.

In hilly regions, populations often clustered around the natural water springs. However, due to increased and unplanned urban development in these regions, springs are deteriorating, and their discharge is declining. Despite the significance of springs as a vital natural resource for the mountainous regions of India, there is no systematic database available on these water sources (Rawat et al., 2018). However, various organizations i.e., NGOs, central government bodies, and state government departments are working to generate information on springs at different levels under various schemes. However, a lack of coordination among these organizations poses challenges, hindering the effective implementation of a national level SSM program. Therefore, it is imperative to devise a systematic, scientific, and coordinated mechanism to take on the challenges posed by declining spring discharge in ensuring water security for future.

Keeping this in view, Department of Water Resources, River Development & Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti, Govt. of India has constituted a Steering Committee on***Springshed Mapping of IHR Including Mountainous Regions of the Country and Springshed Based Watershed Management Plan*** vide Office Order No. T-81011/77/2021-GW Section-MOWR; dated 27 September 2022 with an aim to motivate -mobilize- and monitor the springshed based watershed management plan in the mountainous areas of the country through various water conservation schemes of Central and States. The officials from various agencies/institutions working/dealing with the spring across the country have been identified as members to this Steering Committee (Table 1.1).

Table 1.1: Members of steering committee constituted by DoWR, RD & GR

S. No.	Name, Designation and Department	Committee
1	Sh. Subodh Yadav (IAS), Joint Secretary, DoWR, RD & GR, Ministry of Jal Shakti, Govt. of India	Chairman
2	Chairman, Central Ground Water Board, DoWR, RD & GR, Ministry of Jal Shakti or his representative	Member
3	Director, National Institute of Hydrology, DoWR, RD & GR, Ministry of Jal Shakti	Member
4	Representative, not below the rank of Director, from Brahmaputra Board, Ministry of Jal Shakti, Govt. of India	Member
5	Director, North-Eastern Regional Institute of Water and Land Management, Ministry of Jal Shakti, Govt. of India	Member
6	Director (Watershed Management), Dept. of Land Resources, Ministry of Rural Development, Govt. of India	Member
7	Representative, not below the rank of Director, from Geological Survey of India	Member
8	Dr. Himanshu Kulkrani, Advanced Centre for Water Resources Development and Management (ACWADAM)	Member
9	Representative from Mountainous States, not below the rank of Secretary dealing the subject	Member
10	Er. Kireet Kumar, Sc 'G' & Nodal Officer, NMHS, Govind Ballabh Pant National Institute of Himalayan Environment, MoEF&CC, Govt. of India	Member
11	Prof. Sumit Sen, Professor, IIT Roorkee	Member
12	Prof. Sumedha Chakma, IIT Delhi	Member
13	Representative, not below the rank of Director, from Survey of India	Member
14	Representative, not below the rank of Director, from National Project Monitoring Unit, National Hydrology Project	Member
15	Representative not below the rank of Director from, Department of Rural Development (MGNREGA)	Member
16	Dr. Soban Singh Rawat, Scientist 'F', NIH, Roorkee	Member Secretary

The specific objectives of the steering committee are as follows:

- To initiate/monitor systematic mapping/geo-tagging of springs across the Himalayas/mountainous regions in the country.
- To compile the springs information collected by various Government/non- Government agencies including States and bring them in a common Web-GIS based web-portal.

- To suggest the systematic step-by-step methodology for incorporation of SSM programs including recharge/rejuvenation interventions for their sustainability.
- To develop a coordination mechanism among various stakeholder Ministries for efficient mobilization of resources/funds for SSM.
- To develop capacity among the field functionaries in the field of SSM through planned training and demonstration programs.
- Any other point(s) which the Committee considers fit.

Committee met on 31 January, 2023, 13 March, 2023 at Shram Shakti Bhawan, New Delhi, and 21 July, 2023 at National Institute of Hydrology (NIH), Roorkee and discussed the present status, available resources, scope, bottlenecks, methodologies and capacities of states to handle the challenges in formulation and implementation of the SSM activities in the background of traditional watershed management approach. Committee also organized one brainstorming workshop on***Development of Stranded Operating Procedure (SOP) for Springshed Management*** at NIH, Roorkee on 15 May 2023 which was attended by the representatives of 23 organizations belonging to implementing agencies/research institutes/non-government organizations working in the field of SSM across the country (Annexure-1.1).

1.3 Spring data availability and collection approach

The details of spring mapping are crucial for understanding the extent of the area covered by different agencies and for making an initial assessment of the number of springs that have been identified so far. It is also imperative to understand the methodologies utilized for spring mapping, given that this is a time-consuming process. Furthermore, it is essential to know how various organizations are deploying their workforces for this task. Two primary approaches are (i) Paper-based Data Collection (PDC) and (ii) Electronic Data Collection (EDC), with the former being more time-consuming, expensive, and susceptible to error. Understanding the criteria for selection of spring to be mapped is equally important, as different organizations may have divergent mandates. For example, one organization may only capture the springs that are the primary source of water supply, while others may capture all springs regardless of their location, and some may limit themselves to the village boundary. Such variations in selection criteria may lead to considerable heterogeneity in the data, highlighting the need for common guidelines. The parameters collected during spring mapping are also crucial, as it is a time-consuming and costly endeavour. While springs can be geotagged with only latitude and longitude, capturing such minimalistic information on springs is insufficient to make informed decision at the policy level. The additional information can be in various forms, such as photographs, basic water quality, or general demographic information of dependent populace. However, each additional detail results in increased time, effort, and expenses. For instance, while capturing basic in-situ water quality parameters such as pH or EC is easier, obtaining detailed information on all cations and anions in the laboratory is expensive and time consuming.

To understand the status of available data on spring information available with different central and state government organizations along with the NGOs working in the area of SSM was collected. List of the organizations or agencies which provided the information on surveyed springs is presented in the Table 1.2.

As per the details received it is observed that approximately 60,000 springs have been surveyed across the IHR by various agencies. For further analysis, these organizations were requested to share the geographic coordinates of the springs. However, the information can only be received from the Survey of India (SOI) which has previously compiled the similar information from various organizations viz., CGWB, NIH, RMDD Sikkim, CHIRAG, etc. for IHR. Furthermore, SOI also provided the geographic coordinates of springs for the region other than IHR to enrich the understanding about the spring distribution at PAN India scale. Besides, data pertaining to some of the springs which were mapped under various studies under National Hydrology Project (NHP) were also shared by NHP. This information was analysed to understand the distribution of springs in the Indian landscape (Fig. 1.1).

Table 1.2: List of organizations that have provided data on springs, along with relevant available information.

S. No.	Name of the organization	Spring
	Central Government Organizations	
1	Geological Survey of India (Northern, Western and North-Eastern Region), Ministry of Mines, Govt. of India	203
2	GB Pant National Institute of Himalayan Environment, Ministry of Environment, Forest, and Climate Change, Government of India	6124
3	National Institute of Hydrology, Ministry of Jal Shakti, Govt. of India	2217
4	National Hydrology Project, Ministry of Jal Shakti, Govt. of India	11471
	State Government Departments	
5	State Level Nodal Agency, WDC-PMKSY, Government of Assam	36

1.3. Spring data availability and collection approach

Table 1.2 continued from previous page

S. No.	Name of the organization	Spring
6	State Level Nodal Agency for Watershed Management, Government of Manipur	254
7	Water Resource Department, Government of Meghalaya	7859
8	Institute of Natural Resources, Government of Meghalaya	17005
9	Dept. of Land Resources, Government of Nagaland	2885
10	Dept. of Rural Development, Government of Sikkim	1800
11	Forest Department, Government of Uttarakhand	120
12	Irrigation Research Institute, Government of Uttarakhand	135
13	Watershed Management Directorate (PMKSY-WDC 2.0), Government of Uttarakhand	808
	Non-Governmental Organizations	
14	Grameen Va Paryavaran Kendra (Grampari), Maharashtra	~200
15	Advanced Center for Water Resources Development and Management (ACWADAM), Pune, Maharashtra	10000+
16	Central Himalayan Rural Action Group (CHIRAG), Uttarakhand	2458
17	People's Science Institute (PSI), Dehradun	1172

It is to be noted that attempts were made to omit the repeated information on spring entered due to longitudinal survey or due to mapping by multiple agencies by considering a buffer of 20 m diameter. Springs falling in the overlapping buffers were combined as single spring or single cluster of spring. About 2700 springs were identified to have repeated entries out of the total information available on 48,113 springs (Table 1.3) spread across 525 districts of the country. Furthermore, a threshold of 25 springs was used to find the number of districts across various states wherein the springs may have important role in sustaining the water supply and meeting the demand of local populace (Table 1.4).

Table 1.3: Distribution of springs across various states as per the available 'limited' information.

State	Total Mapped Springs	Count of District (with mapped springs)
Andhra Pradesh	493	12
Arunachal Pradesh	273	23
Assam	334	22
Bihar	119	12
Chhattisgarh	718	25
Dadra & Nagar Haveli & Daman & Diu	18	1
Goa	238	2

Table 1.3 continued from previous page

State	Total Mapped Springs	Count of District (with mapped springs)
Gujarat	209	26
Haryana	18	7
Himachal Pradesh	8890	12
Jammu And Kashmir	7267	22
Jharkhand	582	24
Karnataka	375	27
Kerala	2155	13
Ladakh	687	2
Madhya Pradesh	1354	48
Maharashtra	2596	33
Manipur	432	13
Meghalaya	9300	11
Mizoram	2245	8
Nagaland	375	11
Odisha	987	23
Punjab	30	8
Rajasthan	362	29
Sikkim	749	4
Tamil Nadu	311	26
Telangana	261	27
Tripura	63	6
Uttar Pradesh	147	20
Uttarakhand	6221	13
West Bengal	304	14
Grand Total	**48113***	**525**

Table 1.4: Distribution of springs in states, based on limited data (only districts with > 25 springs included)

State	Total Mapped Springs	Count of District (with mapped springs)
Andhra Pradesh	464	7
Arunachal Pradesh	103	3
Assam	268	5
Bihar	54	2

*Including repeated springs.

Table 1.4 continued from previous page

State	Total Mapped Springs	Count of District (with mapped springs)
Chhattisgarh	626	12
Goa	238	2
Gujarat	92	2
Himachal Pradesh	8890	12
Jammu & Kashmir	7250	21
Jharkhand	431	8
Karnataka	202	4
Kerala	2132	11
Ladakh	687	2
Madhya Pradesh	1117	26
Maharashtra	2452	16
Manipur	372	6
Meghalaya	9300	11
Mizoram	2245	8
Nagaland	341	7
Odisha	824	8
Rajasthan	207	5
Sikkim	749	4
Tamil Nadu	138	2
Telangana	115	3
Tripura	43	1
Uttar Pradesh	42	1
Uttarakhand	6207	11
West Bengal	273	4
Grand Total	**45862***	**204**

A total of 207 districts were identified wherein the count of springs is more than 25, a spatial map representing the same is presented in Fig. 1.2. For several states which have significant mountainous terrain, the spring information available is underwhelming. This infers that either the springs have not been mapped or the information on these resources is not readily accessible. This necessitates the need of a systematic and coordinated efforts to collect information across the country on these vital resources for keeping the stock of water available through these pygmies yet crucial water outlets.

*Including repeated springs.

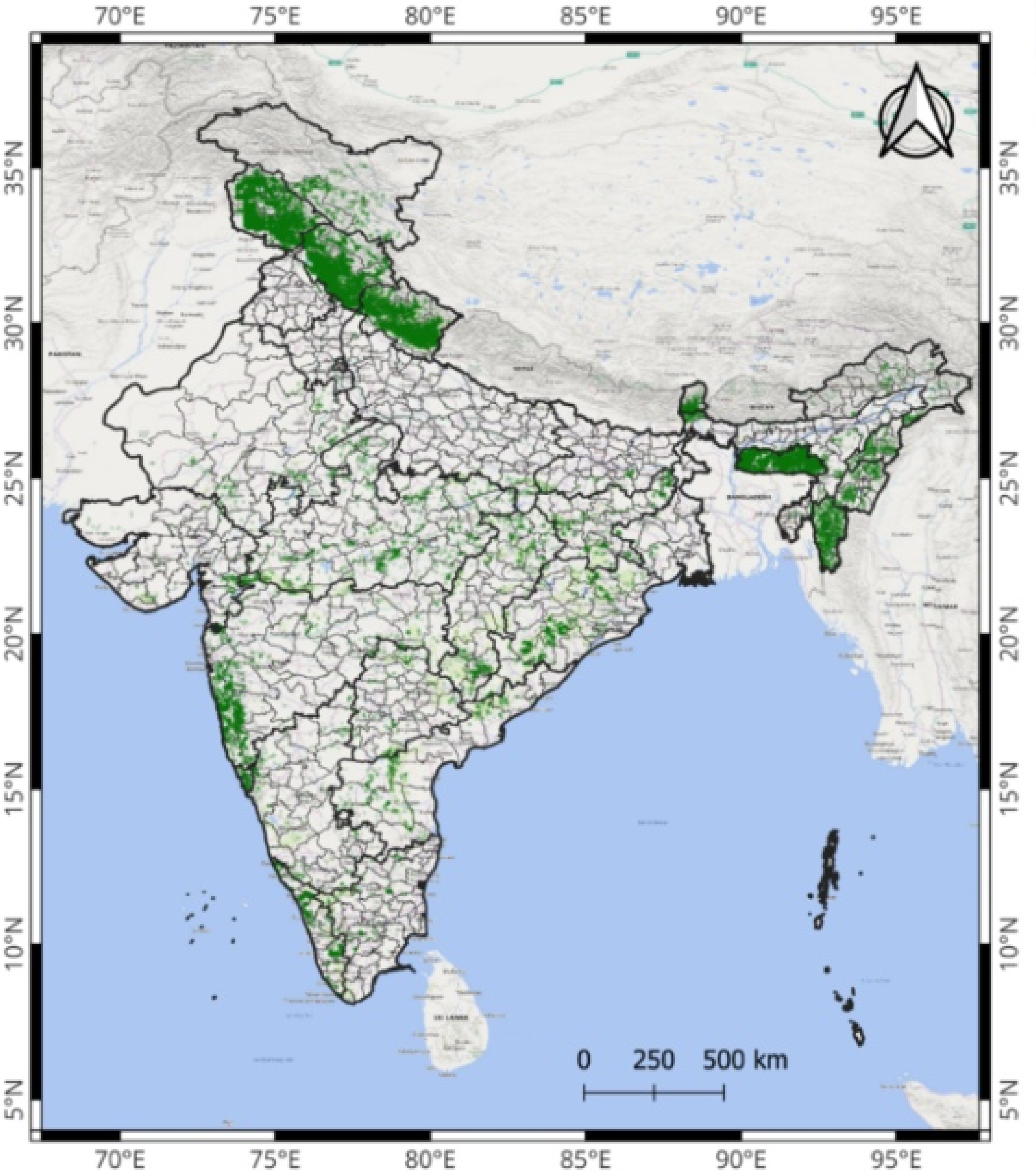


Fig. 1.1 Spring distribution across India as per the information shared by various organizations.

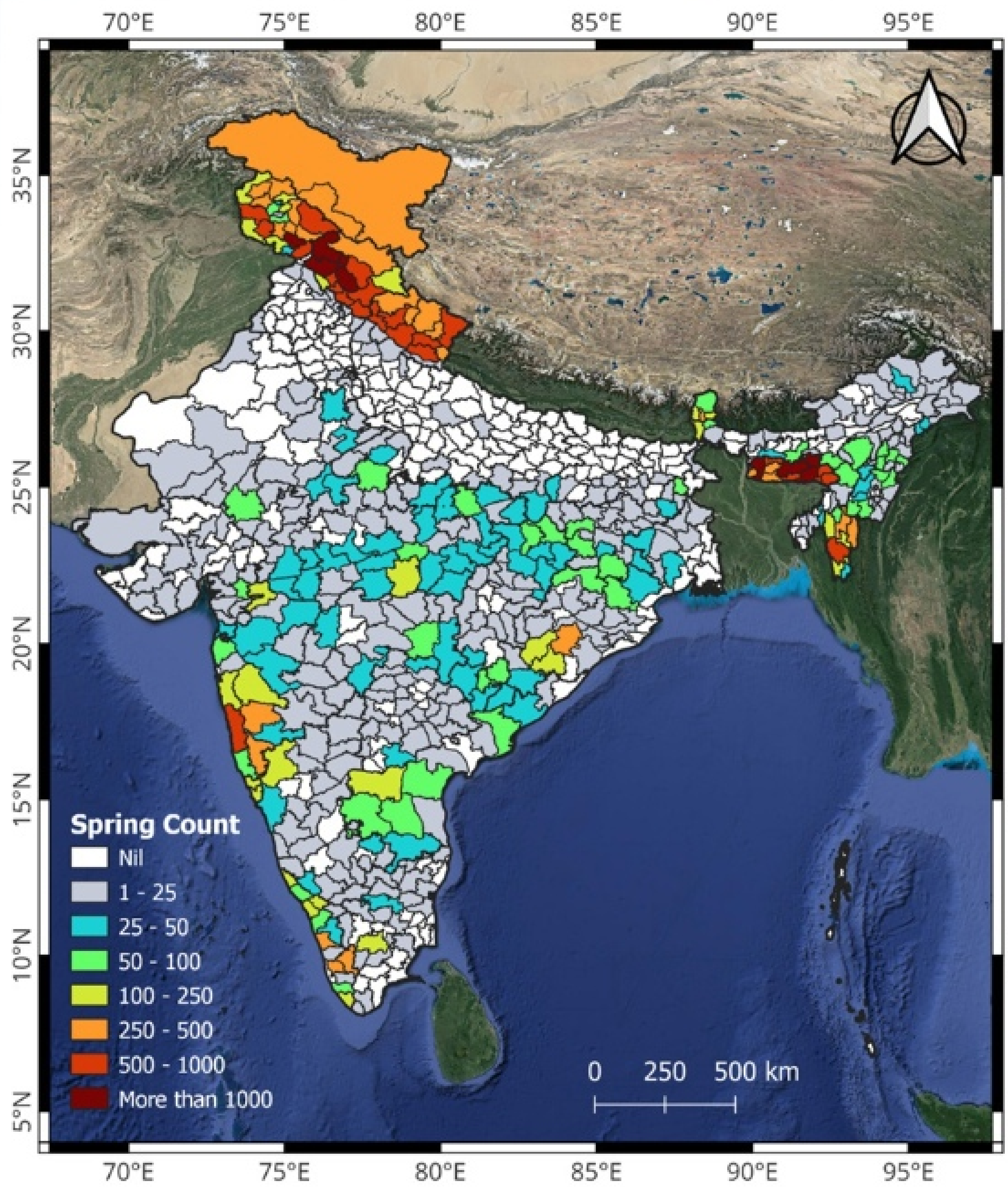


Fig. 1.2 Spring count across different districts of India.

1.4 Need of streamlining the efforts for springshed management

Spring have recently gained the attention in various government initiatives. One of the key mentions would be 'Jal Shakti Abhiyan - Catch the Rain Campaign' for 2022 and 2023 wherein Ministry of Jal Shakti, Government of India was given lot of stress on SSM in mountainous states of the country . Furthermore, in the Jal Jeevan Mission wherein the emphasis is being put on the source sustainability, SSM becomes imperative for the implementing agencies in the hilly regions of the country.

The Department of Land Resources has been implementing a Centrally Sponsored Scheme (CSS) called the 'Integrated Watershed Management Programme' (IWMP) since 2009-10. IWMP was later amalgamated as the Watershed Development Component of PMKSY (WDC-PMKSY) in 2015-16. The WDC-PMKSY has now been continued as 'WDC-PMKSY 2.0' for the project period of 2021-2026. As per the recommendations of NITI Aayog (Niti Aayog, 2018), the rejuvenation of springshed has been incorporated as a new activity within the approved cost of the WDC-PMKSY 2.0. Hence, it is important to know whether the implementing agencies are giving weightage to SSM in their annual action plan to sustain these vital resources. Furthermore, it is important to know the extent of the efforts being made by various implementing agencies on spring treatments to understand the complexities or obstacles that need to be overcome. Agencies draw financial support from different schemes that may come from central government namely, WDC-PMKSY-2.0, MGNREGS, NABARD, etc. or state governments. Funding from industries under Corporate Social Responsibility (CSR) is also availed along with the international support that may come from World Bank or other sources. Therefore, it is vital to be well informed about various avenues from where the financial supports can be drawn for the implementing agencies or NGOs working in the domain of SSM. Moreover, it also helps the policy makers to bring multiple schemes dealing with the same cause under one umbrella to streamline the tracking of funds while reducing the burden on exchequer.

1.5 Capacity building in the domain of springshed management

As Springshed Management (SSM) involves a range of disciplines, it is crucial to provide field functionaries with adequate training to achieve the common objective of spring rejuvenation in fragile mountainous ecosystems. To assess the capacity building requirements and identify the areas that require additional training, it is necessary to have a comprehensive understanding of the existing expertise related to SSM. Therefore, it is important that the implementing agencies possess the expertise on different aspects of springshed management viz., data collection methodology, spring water quality analysis, instrumentation in springshed/watershed, identification of recharge area/springshed, design of recharge measures, social and governance aspects, and impact assessment of springshed/watershed programs. Despite the fact that SSM requires a scientific understanding, majority of the organizations and agencies reported the unavailability of subject matter experts. To ensure the capacity development among the field functionaries as well as the stakeholders, it is essential to develop the standard training module comprising all the essential elements of SSM.

1.6 Conclusion

Various organizations, such as central and state government bodies and NGOs, are working in the domain of SSM and have gather information on springs through different schemes. However, the existing information is scattered, lacking a systematic database available on these water sources. Hence, it is imperative to establish a centralized platform for data management and utilization that aids in the protection and rejuvenation of spring water sources by providing a shared space for policymakers, researchers, and stakeholders. It is also needed to develop the standard guidelines and set of protocol for SSM and spring mapping to ensure the consistency in the information being generated by different organization. Besides, for capacity development, an initiative in the line of Training of Trainers (ToT) can be initiated while developing standard manual and reference materials on SSM. Additionally, a mechanism should be established to facilitate coordinated efforts among various organizations to protect and rejuvenate spring water sources. This resource book focuses on the following key thematic areas, arranged chapterwise, which are essential for SSM:

(1) **Introduction:** This chapter underscores the significance of springs as crucial water sources in mountainous regions, emphasizing the need for coordinated SSM. The establishment of the Steering Committee on springshed mapping reflects a national initiative, addressing challenges like data fragmentation and the absence of standardized guidelines. The chapter highlights the importance of capacity building and sets the stage for detailed exploration of thematic areas in subsequent chapters, aiming to provide a comprehensive guide for sustainable SSM and water security.

(2) **Spring and Its Various Classifications:** The aim of this chapter is twofold: firstly, to differentiate springs from other water bodies, equipping individuals tasked with spring mapping with the necessary skills to accurately identify and map springs in their study areas. Secondly, the chapter provides classifications of springs based on various criteria to enhance the understanding of officials from implementing agencies. This knowledge serves to better manage and steward their springs effectively.

(3) **Sequential Steps for Comprehensive Spring Mapping and Survey:** This chapter outlines a systematic approach to comprehensive spring mapping and surveying for effective SSM. The process involves data mining, Level I field surveys for basic parameters, Level II surveys for detailed information and sample collection, and Level III long-term monitoring of selected sentinel springs. These interconnected steps, emphasizing collaboration with various sources, aim to build a primary database, inform management plans, and contribute to water resource understanding in challenging mountainous terrains.

(4) **Springshed Monitoring and Data Collection:** Chapter 4 emphasizes the critical importance of comprehensive springshed monitoring in the IHR due to the alarming decline of springs and water quality. The chapter details manual and instrumented methods for measuring spring discharge, including the installation of flumes and Automatic Weather Stations. Regular site monitoring, data collection, and analysis are highlighted to provide valuable insights for informed decision-making in water resource management, ensuring the conservation of ecologically sensitive areas for current and future generations.

(5) **Springshed Management Methodology:** This chapter discusses Springshed Management (SSM), an approach addressing water security challenges in mountainous regions like the Himalayas. The methodology includes geological mapping, typology assessment, and community involvement, with a focus on monitoring spring discharge, water quality, and socio-economic impacts. The chapter concludes by recommending the nationwide adoption of the SSM approach, emphasizing collaboration among various agencies for integrated SSM.

(6) **Springs Water Quality Monitoring and Analysis:** This chapter provides comprehensive guidelines for monitoring and analyzing the water quality of springs in India, addressing the urgent need due to rapid population growth and urbanization. The protocol covers sample collection, laboratory analysis, data management, and quality control. This chapter also includes the hydrogeochemical facies of springwater, shading light on chemical composition of originated from natural and anthropogenic sources.

(7) **Application of Environmental Isotopes in Groundwater Hydrology of Springs:** In this chapter, the use of stable isotopes, particularly hydrogen and oxygen, in understanding spring hydrology is highlighted. The chapter emphasizes a suggested sampling protocol, the calculation method for stable isotopes, and the significance of seasonal variability in isotopic signatures. Additionally, it explores the role of isotopes in delineating spring recharge elevations and determining the age of spring water, crucial for effective water resource management.

(8) **Treatment Measures for Springshed Management:** Chapter 8 focuses on treatment measures for SSM, emphasizing the need for a combination of biological/agronomical practices and engineering interventions to revive natural springs. These measures aim to enhance recharge, storage, and control soil erosion in mountainous regions, contributing to springs' sustainability. The chapter advocates an integrated approach, providing Standard Operating Procedures (SOP) for practitioners. In conclusion, the chapter offers comprehensive guidelines for practitioners engaged in SSM, integrating both biological and engineering measures tailored to the specific characteristics of mountainous regions.

(9) **Hydrological Analysis of Spring Flow for Sustainable Springshed Management Programme:** This chapter discusses the hydrological analysis of spring flow for a sustainable SSM program. It emphasizes the importance of discharge data and introduces hydrological indices. The chapter includes a case study of the Dhara Vikas program in Sikkim, analyzing parameters like discharge, hydrograph shape, variability, depletion time, and aquifer recharge. Accurate hydro-metrological data is highlighted as crucial for effective impact assessment in SSM programs.

(10) **Impact Assessment in Springshed Management:** The chapter underscores the importance of baseline surveys in SSM projects, covering aspects like spring discharge, water quality, and socioeconomic factors. It outlines short-term and long-term impacts, categorizing them into ecological, economic, social, and sustainability aspects, with specific indicators and verification methods for each. Emphasizing the need for ongoing monitoring, the chapter provides a detailed framework for assessing the effectiveness and sustainability of SSM initiatives.

(11) **Capacity Building in the Field of Springshed Management:** This chapter discusses the role of the different functionaries involved in various SSM programs along with challenges faced by them. It also categorized the personnel involved in SSM into four groups and accordingly suggest different modules for strengthening their understanding about the SSM.

The detailed elaboration on above listed thematic areas in subsequent chapters will help the readers in developing thorough understanding on various aspects of SSM. This knowledge will contribute to the overarching goal of achieving source sustainability and ensuring a water-secured future particularly in mountainous regions of the country.

Chapter 2

Spring and Its Various Classifications

2.1 Background

The significance of springs cannot be overstated. While they play a crucial role in various ecosystems and human activities, there exists a considerable degree of confusion surrounding their definition. This ambiguity can lead to misidentification and misunderstanding, hindering efforts aimed at their management and conservation. Understanding the geometry of springs is essential for grasping their structural intricacies and hydrological dynamics. Moreover, classifying springs based on their distinct characteristics is paramount for effective SSM and rejuvenation efforts.

To this end, it is imperative to categorize springs according to various parameters such as flow patterns, geo-hydrological conditions, types of lithologies, average discharge rates, seasonal variations in flow, chemical composition of spring water, and spring water temperature. Each of these factors offers valuable insights into the nature and behavior of springs, providing a foundation for informed decision-making and sustainable resource management.

2.2 What is spring?

A spring is a focused discharge of naturally occurring groundwater on the Earth's surface. Normally two kinds of visuals are come-across in the field based on oozing-out behaviour of any spring i.e., (i) Free flow spring, where water releases from a certain head (Fig. 2.1); while (ii) Seep springs, where water seeps from the micro pores of soil/rocks and attain a ponding depth (Fig. 2.2).

Fig. 2.1 Free flow spring

Fig. 2.2 Seep spring

For creating spring inventory, following conditions need to be considered during springs mapping:

(i) Not all naturally occurring groundwater flows with diffuse discharge can be classified as springs. For example:

  (a) **Seepage:** This refers to cases where a discrete discharge point cannot be determined, such as the oozing of groundwater from the banks of a river, lake, or stream, resulting in the creation of a wet and marshy area (Fig. 2.3).

  (b) **Wetlands:** In areas where the water table is near the surface, groundwater discharges diffusely, giving rise to swampy or marshy ecosystems that support unique plant and animal life (Fig. 2.4).

Fig. 2.3 Waterlogging due to seepage

Fig. 2.4 Swampy wetland

(ii) Spring inventory should not include ponds and artificial situations, viz. dug wells, artesian wells, and groundwater that appears in excavations (Figures 2.5, 2.6 and 2.7).

Fig. 2.5 Pond

Fig. 2.6 Dugwell

Fig. 2.7 Artesian well

(iii) Natural springs that have pipes installed at their outlets to direct/guide their flow (Fig. 2.8) should be included in the mapping of springs and should not be mistaken for piped water supplies.

Fig. 2.8 Springs with piped outlet

However, the following should be excluded:

- Pipes connected to artificial tanks and pumping schemes.
- Pipes drawing water from adjoining or nearby streams, rivulets, or Nallahs.

(iv) In addition to free-flowing springs, which are characterized by concentrated flow, there are small and localized groundwater seeps that occur through permeable sediments or fractures in rock, resulting in the formation of pools of water known by different names in local areas, viz. Naula in Uttarakhand, Baowli in Himachal Pradesh, and Bowli/Baowri in Jammu & Kashmir (Fig.

2.9), should also be covered in the spring inventory. It is important not to confuse these with other larger structures like step wells during spring mapping (e.g., Agrasen Ki Baoli in New Delhi, Rani ki Vav in Gujarat, etc.).

Fig. 2.9 Bowli in Udhampur district of J&K

There exists a notable variation in the local nomenclature used to refer to springs across different regions of India. Consequently, it is advisable to incorporate the specific vernacular designations utilized by the local populace when conducting spring mapping exercises. A 'non-exhaustive' list of popular nomenclatures for springs in different regions of India is provided below:

Table 2.1: Local nomenclature of springs across different states of India

S. No.	State	Local nomenclature of spring
1	Arunachal Pradesh	Hikur *(by the people of Adi tribe)* Sadang *(by the people of Nyishi tribe)*
2	Assam	Uuh, Nizara, Juri, Jharna *(in Assamese)* Jarani *(in Dimasa language)* Nijra *(in Bodo language)*
3	Himachal Pradesh	Panihar, Nadu, Baori, Chharedu
4	Jammu and Kashmir	Chashma, Naag, Baowli
5	Karnataka	Neerina bugge, Karanji neeru, Oravu
6	Kerala	Jaladhara, Oat vellum
7	Ladakh	Chhumik

Table 2.1 continued from previous page

S. No.	State	Local nomenclature of spring
8	Maharashtra	Jara or Zara
9	Manipuri	Ephut*(by Meitei people)*
10	Meghalaya	Chimik*(by Garo tribes)*
11	Mizoram	Sih
12	Nagaland	Dzuluo*(in Kohima district)*, Aghokiti*(in Zunheboto district)*, Tzubuk*(in Mokokchung district)*, Tchukvu*(in Wokha district)*, Dzuri*(in Phek area)*, and Tchulan*(in Wokha area)*
13	Sikkim	Dhara, Umrey ko Pani*(Nepali)*
14	Tripura	Hathai-ni*(by the indigenous people)*, and Jharna*(by Bengali people)*
15	Uttarakhand	Naula, Panera*(in Kumaon region)*, and Dhara, Panera*(in Garhwal region)*

2.3 Geometry of spring

Springs are the manifestation of ground water resources of a catchment in the mountainous area. Spring emerging point is called threshold point and it is also a constant drawdown point till the spring is active. The size of springs is influenced by the characteristics of the underlying aquifer, with a poor transmissive aquifer giving rise to small springs and a thick transmissive aquifer leading to larger springs. Despite the common perception of springs as simple water holes, their hydrogeology is complex. The hydrological system of a spring comprises three zones: (i) recharge zone, (ii) transition zone, and (iii) threshold point or discharge outlet (Fig. 2.10). The spring's threshold point lies at the end of the transition zone. In the recharge zone the flow has been assumed to be in vertical direction and in the transition zone, the flow has been assumed to satisfy Dupuit-Forchhemier assumptions.

Interestingly, all these three zones are geographically separate (Fig. 2.11). Therefore, yield and flow trend of any spring is influenced by the parameters of recharge zone as well as transition zone and threshold point. Probably, these are the reasons which make SSM complicated unlike to traditional watershed management approach. Sometime recharge area of a spring may lie in multiple watersheds (Fig.

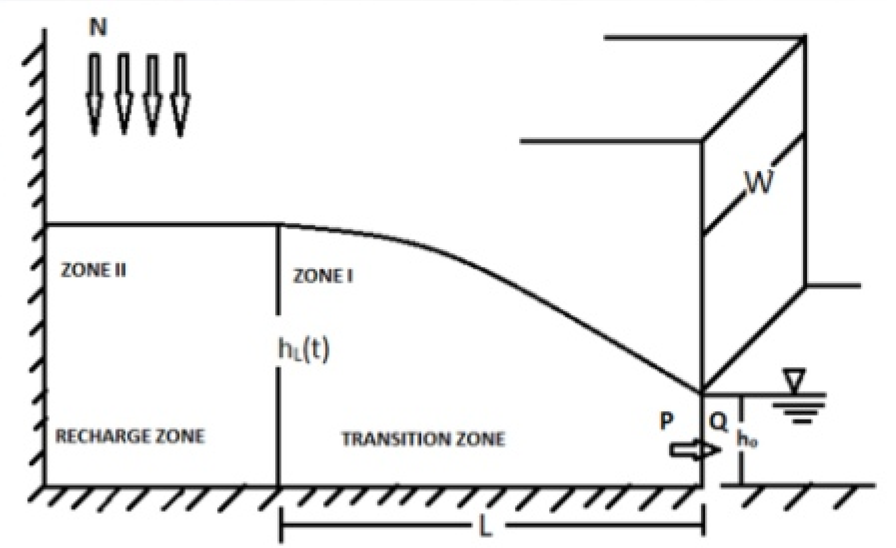


Fig. 2.10 Schematic diagram of spring

2.11), and in such case springshed treatment measures have to be taken in outside of boundary of that watershed in which spring is actually emerging.

2.4 Classifications of springs

The springs manifested at those places where groundwater flow naturally from rock sediment or soil onto the land surface. Their occurrence and magnitude of yield mainly depend on factors such as climate, geomorphology, lithology, fracture density and pattern, and the present-day intensity and orientation of the regional stress field (Pacheco & Alencoão, 2006; Pitts & Alfaro, 2001). Springs can be classified based on the following characteristics:

- Spring flow
- Geo-hydrological conditions
- Types of lithologies
- Average discharge
- Season
- Chemical composition
- Calculated Discharge Variability Ratio (DVR)
- Temperature of spring water

(Modified from Jambay & Uden (2022))

Fig. 2.11 Different components of the spring system

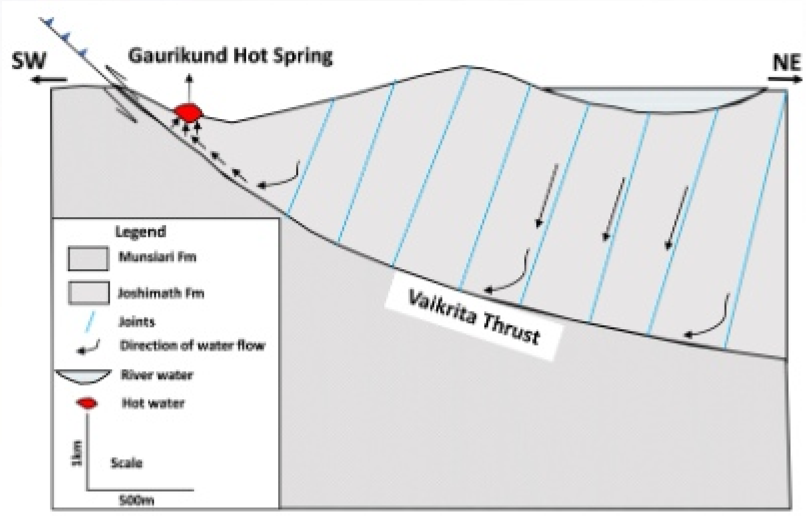
2.4.1 Classification on the basis of spring flow

Bryan (1919) divided all the springs in two categories:

(i) **Gravitational springs:** Springs those resulting from gravitational forces, with water flowing from higher reaches to lower reaches as subsurface flow, emerging where conducive conditions are formed.

(ii) **Non-gravitational springs:** Springs those resulting from non-gravitational forces. These include volcanic springs, associated with volcanic rocks, and fissure springs, resulting from fractures extending to the great depths in the earth crust. Such springs are usually thermal (Fig. 2.12). Sometime such springs are also called artesian springs as water release from this type of springs is due to under pressure. However, it is emphasized here that water come out on the earth surface through a fault/fracture not from a pipe installed by human.

Thermal springs occur along the major faults, fractures or joints. These major fault systems provide the channels for the circulation of meteoric cold water to depths where the normal geothermal temperature gradient heats it up and then returned to the surface in the form of hot or warm springs.



(Source: CGWB)

Fig. 2.12 Schematic diagram showing the genesis of a thermal spring

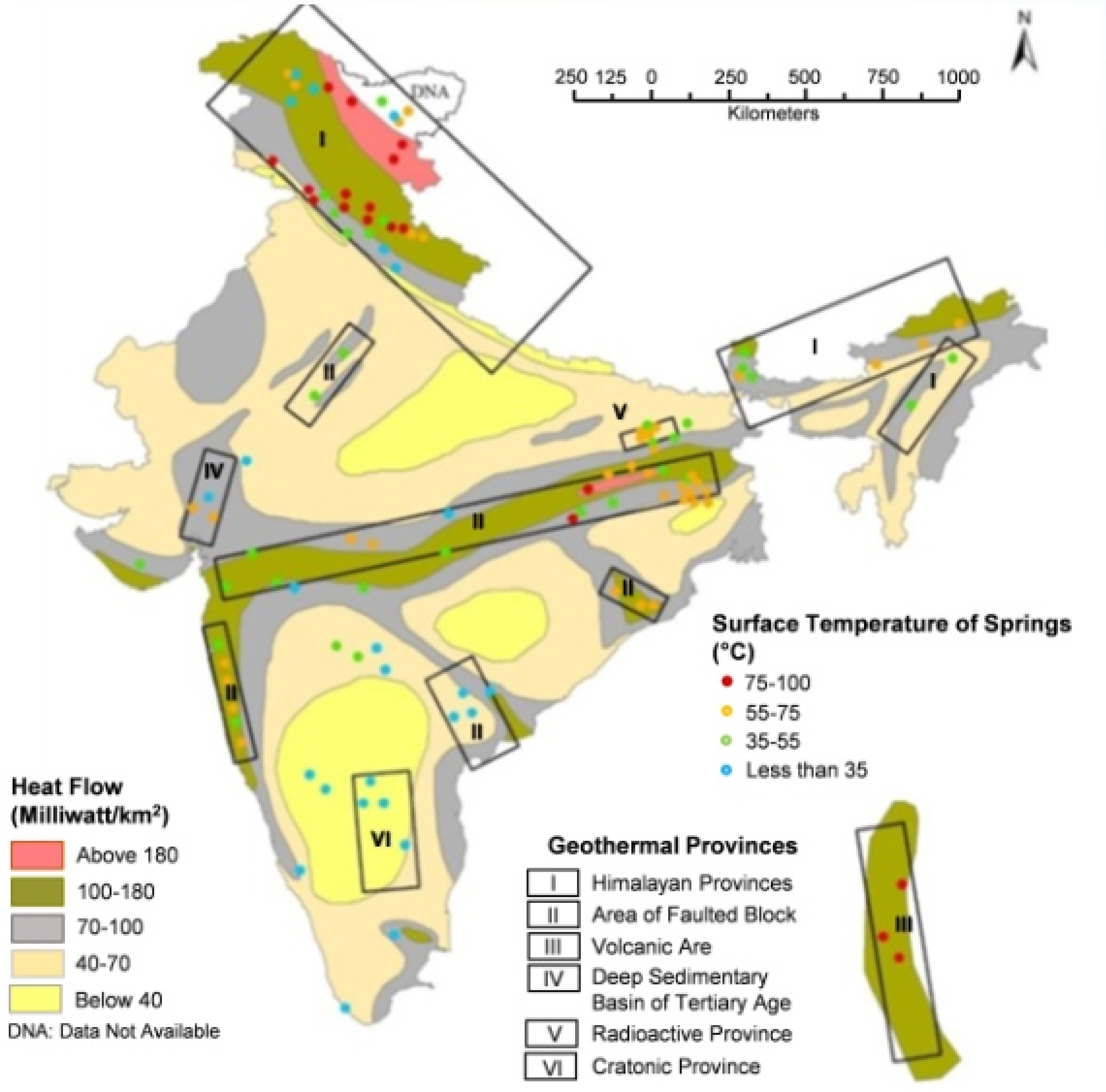
Geological Survey of India (GSI) has classified the entire country into seven geothermal provinces (Fig. 2.13) based upon heat flow values, i.e., >180, 100-180, 70-100, 40-70, and >40 mW/km^2. Heat more than 40 mW/km^2 is sufficient to discharge a hot spring with more than 35 ^oC surface temperature. These heat flux provinces discharge about 400 thermal springs in the jurisdiction of India (Shanker et al., 1991).

2.4.2 Classification on the basis of geo-hydrological conditions

(i) **Depression springs:** These springs discharge where the ground surface intersects the water table, representing the upper surface of the aquifer (Fig. 2.14a). Such springs are generally found in undulating topography where slopes change abruptly and the water table tends to intersect the topography in depressions.

(ii) **Contact springs:** These springs where a permeable water bearing formation overlies a less permeable or impermeable formation intersects the ground surface (Fig. 2.14b). Occurrence of a number of springs in a horizontal line pattern indicate the existence of contact springs in the area.

(iii) **Fracture/fault spring:** These springs originate from water-bearing fractures or faults in the Earth's crust that intersect the topography along specific areas.



(Source: GSI)

Fig. 2.13 Various geothermal provinces, identified by GSI, responsible for the genesis of varied temperature thermal springs in the country

In these springs, water seeps into the ground, navigating through geological fractures or faults, and eventually emerges as a spring on the Earth's surface (Fig. 2.14c). Genesis of number of springs along a vertical line pattern are the indication of fracture or fault springs in the area.

(iv) **Karst springs:** These springs are the typical example of springs originating from limestone or dolomite lithology. In Karst springs, water flow within sinkholes or cavities formed in carbonate rocks due to the dissolution of rock material by chemical action (Fig. 2.14d). Over time, these cavities get enlarged due to continuous dissolution, forming caves from which groundwater emerges.

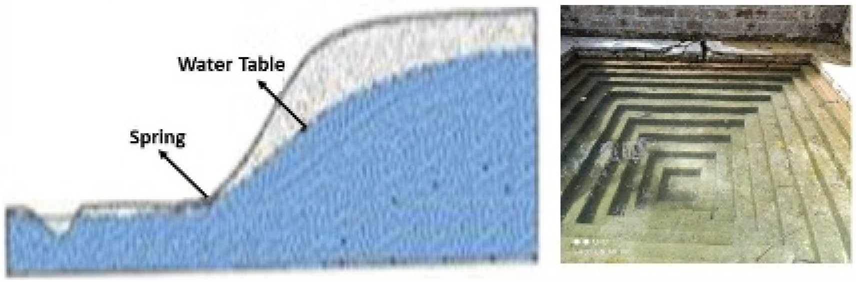
2.4.3 Classification on the basis of types of lithologies

It has been observed that lithologies, influenced by their characteristics and hydraulic parameters (porosity, permeability, storage coefficient) play a significant role in the recharge behavior of springs. Pérez (1996) classified the flow of spring according to lithology in nine groups:

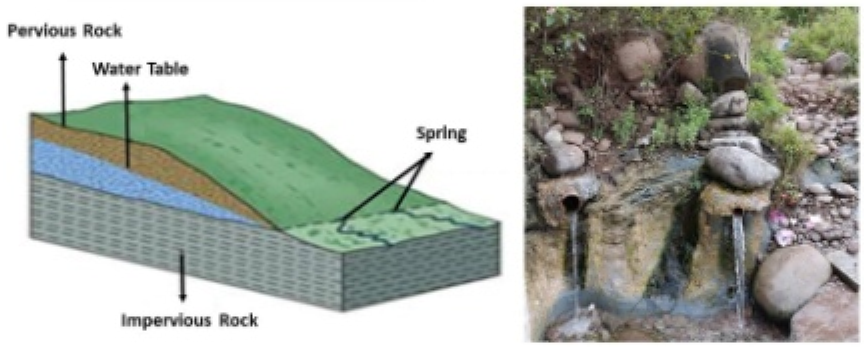
- Alluvial sediments; sand and gravels
- Conglomerates
- Sandstones
- Calcarenites, fractured limestones, karstic limestones, dolomites, marbles, tuff
- Marls, limery marls, silts, clays
- Quartzites
- Slates, schists
- Plutonic rocks, gneisses, dykes
- Other rocks: gypsum, volcanic rocks

2.4.4 Classification on the basis of average discharge

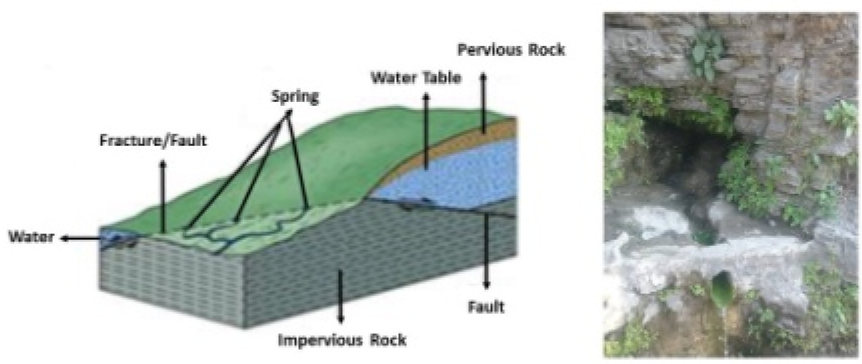
Meinzer (1923) classified the springs according to their mean discharge and this classification (Table 2.2) has been in use for many years in the United States. In India most of the springs are small flow springs and lies in the category of Sixth and Seventh of Meinzer classification. Such classification which limited Indian springs in only two categories need to be redefined.



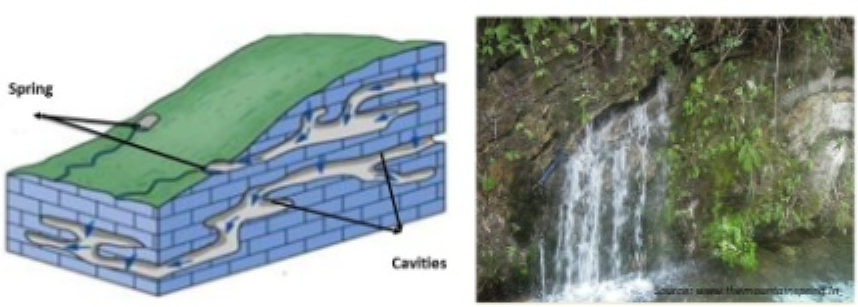
(a) Conceptual diagram of depression spring



(b) Conceptual diagram of contact spring



(c) Conceptual diagram of fracture/fault spring



(d) Conceptual diagram of karst spring

Fig. 2.14 Different type of springs on the basis of geo-hydrological conditions

Table 2.2: Classification of springs on the basis of discharge

Magnitude	Average spring discharge
First	$>10m^3/s$
Second	$1\text{-}10m^3/s$
Their	$0.1\text{-}1m^3/s$
Fourth	$10\text{-}100l/s$
Fifth	$1\text{-}10l/s$
Sixth	$0.1\text{-}1l/s$
Seventh	$10\text{-}100ml/s$
Eighth	$<10ml/s$

2.4.5 Classification on the basis of seasonality of flow

(i) **Intermittent springs:** These springs exhibit discharge only during a part of the year when there is sufficient groundwater recharge to sustain the flow. Such springs are not reliable as sources of water throughout the year, however there is scope to increase their longevity.

(ii) **Perennial springs:**Perennial springs discharge throughout the year and often tap extensive aquifer in a region.

2.4.6 Classification on the basis of chemical composition of the spring's water

Clarke (1924) assumed that the chemical composition of water would indicate the geologic origin of the spring. Clark decided that the chemical composition of the water allowed for a more definite classification system and a better comparison of springs. He simply used a classification of waters based on their negative radicals (anion) and applied it to springs. Classification of springs based on the chemical composition of water is provided in Table 2.3.

Table 2.3: Classification of springs on the basis of chemical composition of water

Spring Type	Characteristics
Chloride waters	principal negative ion Cl
Sulphate waters	principal negative ion SO_4
Sulphate-chloride waters	with SO_4 and Cl both abundant
Carbonate waters	principal negative ion CO_3 or HCO_3
Sulfphatocarbonate waters	SO_4 and CO_3 both abundant
Chlorocarbonate waters	Cl and CO_3 both abundant
Triple waters	containing chlorides, sulphates, and carbonates in equitable amounts
Siliceous waters	rich in SiO_2
Borate waters	principal negative radical B_4O_7
Nitrate waters	principal negative ion NO_3

2.4.7 Classification on the basis of calculated Discharge Variability Ratio (DVR)

Alfaro & Wallace (1994) used flow duration statistics to estimate the calculated Discharge Variability Ratio (DVR). Mathematical expression to estimate DVR is as follows:

$$DVR = \frac{Q_{10\%}}{Q_{90\%}} \tag{2.1}$$

where, $Q_{10\%}$ is the high flow exceeded 10% of the time and $Q_{90\%}$ is the low flow exceeded 90% of the time.

This classification is hydrologically very important and DVR value can be used for selection of the reliable springs for tapping water supply schemes. A spring having low DVR value is considered as good option for the reliable water supply. Classification of springs based on DVR is provided in Table 2.4

Table 2.4: Classification of springs on the basis of DVR

Type of spring	$Q_{10\%}/Q_{90\%}$
Steady (extraordinarily balanced)	1.0 - 2.5

Table 2.4 continued from previous page

Type of spring	$Q_{10\%}/Q_{90\%}$
Moderately (well) balanced	2.6 - 5.0
Balanced	5.1 - 7.5
Moderately unbalanced	7.6 - 10.0
Highly unsteady (extraordinarily unbalanced)	>10.0
Ephemeral/seasonal	Infinite

2.4.8 Classification on the basis of spring's water temperature

Springs are grouped into five classes according to their water temperature, with the classification determined by comparing the spring water temperature to the mean annual air temperature (Table 2.5).

Table 2.5: Classification of springs on the basis of water temperature

Type of Spring	Criteria
Cold	Below mean annual ambient temperature
Normal	Within 12.2°C of the mean ambient air temperature
Geothermal-warm	>12.2°C warmer than mean annual ambient temperature, but <37.8°C
Hot	Significantly warmer than mean annual ambient temperature 37.8°C to 100°C
Superheated (Usually pressurized)	>100°C

The purpose of giving various classifications is to understand various parameters which play the major role in the genesis of spring and how these parameters control the quantity and quality of spring water. The use of a particular classification or a combination of classifications is governed by the purpose behind classifying springs in an area. The typology of springs in an area is often the first indicator of their reasons for drying up as well as the location and nature of interventions that must be considered for their revival or restoration.

Chapter 3

Sequential Steps for Comprehensive Spring Mapping and Survey

3.1 Background

The revival of springs is the need of the hour and requires concrete planning based on scientific studies augmenting the valuable folk knowledge of this precious resource. Based on collective experience of scientists, researchers, and domain experts from different government and NGOs, it is evident that the condition of springs throughout the country is broadly similar. An overwhelmingly majority of springs have been reported to exhibit a declining trend in their discharge. The rate of spring drying or declining water yield may vary from place to place due to pace of changing Land Use and Land Cover (LULC) and regional effect of climate change. Therefore, achieving their revival necessitates a systematic and well-planned strategy across the mountainous regions of the country.

It is well known and advocated in the NITI Aayog working group report (NITI Aayog, 2018) that springs could not find due importance in our policy so far, primarily because of the lack of a basic scientific database on springs in the IHR which is also true for other mountainous states. Local people understand their significance in their daily lives, however, due to the unavailability of readily accessible information, these springs have consistently been neglected both at the policy and implementation levels. As the saying goes,*'You can't manage what you don't measure'*, the availability of a primary database on springs will be of utmost importance and immensely useful for the formulation of a realistic, robust, and replicable SSM plan.

Mapping is the initial step towards building the primary database on springs. The mapping of a spring involves tagging it on a geo-spatial data platform, which comprises multiple GIS layers of information. Various types of data viz. hydrological, geological, social, morphological, chemical information pertaining to springs are to be collected through extensive survey in the catchment while conducting the mapping exercise. Mapping also encompasses the establishment of a comprehensive inventory of springs within the designated geographical region, thereby conferring the following merits:

(1) **Facilitation of Comprehensive Assessment:** The systematic mapping process facilitates a thorough comprehension of the current state of springs within the study area.

(2) **Identification of Vulnerable Springs:** This approach aids in the precise identification of springs that are susceptible to degradation or depletion within the catchment area, enabling the prioritization of resources for their restoration and preservation.

(3) **Foundational Document for Springshed Management:** The resulting inventory serves as a foundational document essential for the development and implementation of a scientifically informed SSM plan.

(4) **Framework for Impact Assessment:** It further establishes the framework for conducting a rigorous impact assessment of the SSM program, thereby enabling the evaluation of its effectiveness and outcomes.

(5) **Enhanced Water Availability Assessment:**Particularly pertinent to mountainous regions of the country, this mapping exercise has the potential to greatly aid in the assessment of water availability, contributing to a more robust understanding of this vital resource in such challenging terrains.

The mapping of springs requires an extensive survey which should be meticulously conducted throughout the specified catchment or region of interest. The survey protocols for spring mapping may be systematically organized into four distinct stages:

(1) **Data Mining and Compilation:** In this initial stage, existing information relevant to springs is methodically compiled, drawing upon available data sources and repositories.

(2) **Level I Field Survey:** Subsequently, the first field survey level (Level I) is executed, entailing the geo-tagging of springs directly in the field, along with the recording of fundamental data attributes associated with these springs.

(3) **Level II Field Survey:** Following the Level I survey, the investigation progresses to Level II, wherein a subset of identified springs is judiciously selected for sampling. Geochemical analyses are conducted on these selected springs, generating vital baseline data for future studies and assessment.

(4) **Level III Field Survey:** The final stage, Level III, involves the continuous monitoring of selected reference or sentinel springs. This ongoing monitoring provides valuable insights into the dynamic behavior of these critical springs over time, contributing to a comprehensive understanding of their functioning within the ecosystem.

3.1.1 Data mining and compilation

Data mining essentially refers to the process of searching for and incorporating existing inventories and historical spring-related data into the database. Several valuable sources can be utilized for data mining:

- Survey of India (SOI) has located numerous major springs in the mountainous regions, which are documented in its toposheets. Therefore, SOI toposheets (at least 1:50,000 scale) serve as the most authentic document for obtaining the location of some of the major springs (Fig. 3.1). Information available in the SOI toposheets also provides valuable insight about the spring density in the area of interest, aiding in the formulation of survey strategies for the study area. SOI has provided a copy of data in GIS-vector form for the entire country comprising the geographical locations of the springs. The organizations working in the field of SSM may get the data belonging to their concerned area by requesting to National Institute of Hydrology, Roorkee.
- Reports and other technical documents from academic & research institutions.
- Departments in the states such as Forest, Jal Shakti Vibhag, Land Resources, Water Resources, Soil & Water Conservation, etc. are also monitoring springs in their various schemes. Some specific departments in states viz., Meghalaya Basin Development Authority (MBDA) in Meghalaya, Rural Management & Development Department (RMDD) in Sikkim; Watershed Management Directorate in Uttarakhand; etc. have lot of information on springs.

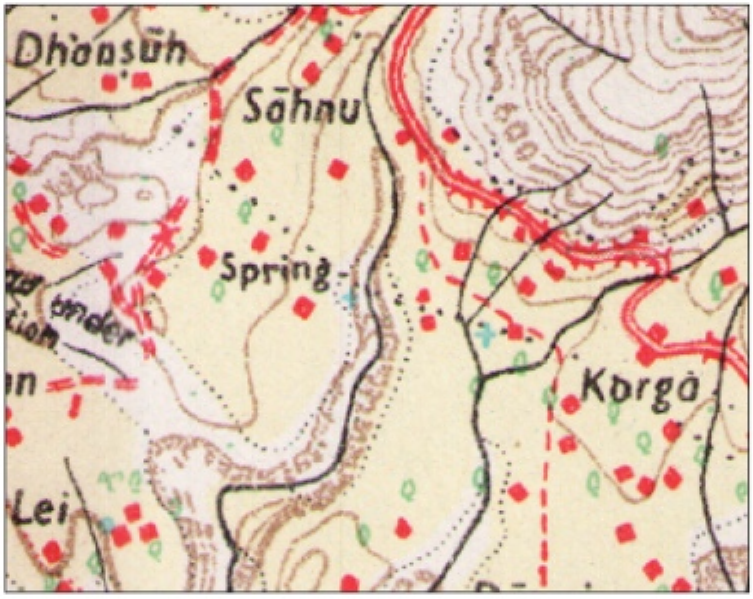


Fig. 3.1 SOI toposheet showing the spring location

- Government academic and research institutes like National Institute of Hydrology (NIH), Roorkee; GB Pant National Institute of Himalayan Environment (GBPINHE), Almora, Department of Land Resources (DoLR), New Delhi; IIT Roorkee, etc.
- Non-Governmental Organizations (NGOs) operating in rural areas viz., Advanced Center for Water Resources Development and Management (ACWADAM), Pune; People Science Institute (PSI), Dehradun; Central Himalayan Rural Action Group (CHIRAG), Nainital; Himmotthan (Tata Trust), Dehradun; GRAMPARI, Panchgani; Center for Ecology Development and Research (CEDAR) etc.

3.1.2 Level I field survey

The objective of the Level I field survey is to identify springs within the study area and gather specific basic parameters that do not require specialized training or equipment. The key characteristics of the Level I field survey are outlined below:

- Mapping a spring typically takes 10 to 20 minutes.

- Limited field equipment is required for Level I reconnaissance surveys.
- Handhelds GPS devices with camera (Fig. 3.2), smartphones with customized applications, can be easily employed for geotagging the springs.

Fig. 3.2 Geotagging of spring with handheld GPS

- Blank survey forms should be carried as a backup in case of mobile or other electronic gadget malfunctions to record spring information.
- It is advisable to carry a container with a known volume, such as a gallon jug or graduated bucket, for discharge measurements.
- A collapsible stopwatch or other timekeeping device, such as mobile stopwatch, can be used to record time for estimating the spring discharge.

The format of the Level I survey is given in Annexure 3.1.

The parameters to be collected during Level I survey were determined through a brainstorming workshop titled 'Development of Standard Operating Procedure (SOP) for springshed management. This one-day, in-person brainstorming workshop brought together Scientists/Engineers/NGOs Executives/Researchers/Field Functionaries from 23 institutions across the country. Utility of a parameter and its feasibility in collection in the field are the key points which were considered in devising the format for Level I survey. This format is also being adopted by the Dept. of

Water Resources, River Development & Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti, Govt. of India for the conductance of 1st Spring Census in the country.

3.1.3 Level II field survey

Level II survey represents an advanced phase of Level I survey, during which agencies are expected to collect more detailed information.

(i) **Purpose of Level II Surveys:**

- To establish a detailed baseline to support future studies such as the impact of climate change, LULC changes, new management strategies and interventions and related areas.
- To quantify the physio-chemical and biotic characteristics of springs
- To identify springs suitable for long term monitoring programs and statistically validated sampling programs for special purposes.

For a detailed description of the data format to be collected during the Level II Survey, please refer to Annexure 3.2.

(ii) **Sample collection for Level II survey:**

Level II survey differs from Level I Survey as it comprises intensive sampling of spring water to assess its physio-chemical, biotic, and isotopic characteristics.

The chemical characteristics of spring water are crucial for understanding their implications on human and environmental health. It can also provide insights into the geologic materials through the water has traveled, the recharge environment, and the residence time. To ensure the accurate inferences, samples must be collected as close to the springhead as possible, recording the standard field parameters along with the geographic coordinates at the time of sampling. GPS coordinates of the sampling locations must be recorded during the time of collection.

Four separate aliquots of samples to be collected during the Level II survey:

- **Alkalinity determination:**Collection of unfiltered and unacidified samples in $60\,ml$ bottles for measuring HCO_3 concentrations using titration method on the same day of sampling.

- **Major cations (Ca^{2+},Mg^{2+},Na^{+} &K^{+}) and anions analysis (F , Cl , $NO3$, SO_4^2 and PO_4^3):** Collection of filtered and unacidified samples in 60 ml bottles for measurement by Ion Chromatographic (IC) unit.
- **Heavy metal analysis:** Collection of acidified samples in 15mlbottles filtered through 0.45-micron Millipore filter paper and preserved with 15 μl 15.8M HNO_3 to $pH \sim 2$, followed by Inductively Coupled Plasma Mass Spectrometry (ICPMS) analysis.
- **Bacteriological analysis:** Collection of unfiltered and unacidified samples 100mlsample in autoclavable bottles store at4 °C and to be analyzed within 24 hours.

For those interested in identifying the recharge source and recharge area of the spring, additional samples can be collected:

- **Environment isotopic analysis:** Collection of unfiltered and unacidified samples in 15 ml for measuring stable isotopes of δ^2H and $\delta^{18}O$ analysis. Ensure that no air bubbles are present in the samples and store at4 °C.
- **Tritium analysis:** Collection of unfiltered and unacidified samples in 500$ml$for measuring radioactive tritium concentration.

3.1.4 Level III field survey

Level III surveys involve the long-term monitoring of selected reference/ vulnerable/ sentinel springs (Fig. 3.3), specifically chosen to develop comprehensive understanding. Sentinel springs are typically representative of a particular aquifer, ecosystem, or region, and may have unusual characteristics such as their chemistry or biota.

Springs selected for Level III survey are based on the information collected during the Level II survey. It is expected to the state agencies concerned will choose at least one spring in each district for level III field survey.

(Source: FRI, Dehradun)

Fig. 3.3 Establishment of monitoring station for Level III survey

Chapter 4

Springshed Monitoring and Data Collection

4.1 Background

The drying up of springs has exacerbated water insecurity for several communities in the IHR. According to a NITI Aayog report (NITI Aayog, 2018), nearly 50% of springs in the IHR have dried up or are exhibiting declined discharge. The quality of spring water has also degraded which is affecting the portability of water. This situation impacts on rural water security, river flows, riparian and wetland ecosystems, and biodiversity. A changing climate is anticipated to intensify these problems further. Over the past decade, growing concerns about the drying up and intermittent nature of springs, coupled with a sustained decline in discharge, have prompted the need for quantitative evidence. The seasonal and overall decline in spring flows have affected domestic water availability in vulnerable Himalayan villages, as well as agricultural productivity since springs are an essential livelihood source in the Himalayas. Agricultural productivity has also been impacted, given that springs play a vital role in the livelihoods of communities in the Himalayas. The same can be juxtaposed on any other catchment located in other mountainous regions of the country. Therefore, a robust management protocol is needed that can be scaled across the mountainous areas. Integrated monitoring could provide resource managers with early evidence of emerging trends and insight to water dynamics in local and regional mountain processes.

Therefore, it is imperative to conduct comprehensive SSM studies in order to facilitate substantial enhancements, notably through the establishment of long-term experimental springshed observatories in different geo-hydro-climatological settings. These observatories will serve as the cornerstone for robust water resource management initiatives in the mountainous regions of the country. In addition, these observatories will be of immense importance in generating the high-resolution, multi-scale, and high-quality long-term datasets, thereby creating a platform for interdisciplinary hydrological research. With such progress, informed decision-making and sustainable water resource management practices can be achieved, ensuring the conservation of ecologically sensitive areas and securing its water resources for the benefit of present and future generations.

Springshed monitoring studies encompass the investigation of hydrologic dynamics and water flow patterns within a specific geographic area to understand the behavior of springs and their response to environmental changes.

4.2 Springshed parameter

Spring flows, pH, electrical conductivity, spring water temperature, hydrometeorological data, soil moisture.

For a springshed monitoring project, a preliminary field campaign needs to be conducted to inventory the springs in the target project area. Following is the standard procedure of springshed monitoring:

(a) **Selection of study site (springshed):** Selection of study area involve identifying a specific spring for monitoring considering the relevant factors such as its significance, accessibility, environmental sensitivity, and potential anthropogenic impacts.

(b) **Manual measurement of Discharge:** Spring discharge constitutes the most fundamental measurement in the case of a study or project on spring water. Springs can be categorized into two types: (i) Free flow springs, which have a constant stream of water flowing out of them in a concentrated manner, and (ii) Seep springs, which receive water through seepage in a diffused manner, unlike a concentrated flow. Manual spring discharge measurements for both types of springs are simple but require different strategies.

For free flow springs, manual discharge measurement is carried out in the following steps.

- Collect the known volume of water in a graduated bucket or water collecting cane (Fig. 4.1).

- Take the average of three measurements: the volume of water collected, and the time taken to collect the water.
- Calculate the spring discharge by dividing the volume by the time taken to collect the water.
- In case of, daily monitoring the time of measurement must be fixed as diurnal cycle of evapotranspiration can affect the spring discharge.
- If there are multiple openings, measure the total discharge of each separately and then sum the flow rates to estimate the spring's total discharge.

For seep springs, manual discharge measurement (Fig. 4.2) is carried out in the following steps.

- Mark the level of water in the chamber.
- Remove a known volume of water from the chamber seep.
- Record the time taken by the water to attain its previous level.
- Calculate the spring discharge by dividing the volume by the time taken to collect the water.

Manual observations are always considered very accurate method of gauging; however, they have certain limitation:

- More frequent observations (say hourly or lesser time interval) are practically not possible.
- High flow spring cannot be measures due to limitation of bucket size.
- Accessibility and harsh weather condition normally prevailing in the mountainous areas discourage to performed regular monitoring of springs.
- Springs having large variability could not be gauged properly.
- Need more manpower to take the observations.

4.3 Instrumentation of springshed

To overcome the limitation of the manual observation of the spring discharge, sites selected for monitoring should be instrumented with flumes or other suitable devices for measuring spring discharge following the reconnaissance survey.

Fig. 4.1 Discharge measurement of a free flow spring

Fig. 4.2 Discharge measurement of a Seep type spring

4.3.1 Flume

Originally, flumes were developed for the measurement of runoff from small agricultural watershed, however in recent time their application have been successfully extended for the measurement of discharge of springs. The major advantage of these instruments is that only by knowing the one parameter i.e., height of the water above the crest is sufficient to estimate the spring discharge. Height of water level above the crest can be measured by capacitance-based water logger or sometime pressure-based transducer. However, selection of different shape of flumes (Fig. 4.3) will be decided based on the physical condition of the oozing-out of the water from the ground surface and hence advisable a field visit of the spring site before selection. Moreover, measuring the 'head' created at the flume as a proxy to the volume-flow rate (discharge rate) of the spring, requires a careful calibration of the system. A head-discharge relationship has to be established for each of the flumes and the selection of a specific flume for a site.

Fig. 4.3 Different shapes flume appropriate to the shape of spring openings

There are certain characteristics of the flumes which make them suitable for measurement of spring discharge:

- Flumes in general tend to be self-cleaning as the velocity of flow is high and there is no 'dam' across the flow stream.
- With a variety of cross-sections available, flumes can be readily integrated into trapezoidal irrigation channels, round pipes, and rectangular channels.
- However, it's important to note that the fabrication costs for flumes are generally higher than the weirs. This is because constructing a flume typically requires more materials than building a weir.

4.3. Instrumentation of springshed

For low flow measurement of spring discharge HS Flumes, Medium flow H Flume, and high flow HL flumes are normally used.

Installation of flume and water level sensor:

This involves the installation of HS flumes with capacitance water level probes at the spring flows located within the selected springshed (Fig. 4.4). The installation of an HS flume and water level sensor comprises the following procedural steps:

- Selection of a suitable location within the waterway for flume installation, considering factors such as flow characteristics and accessibility.
- Precise placement and secure fixation of HS flumes within the waterways to establish the desired flow channels, ensuring accurate measurement of water level and flow rate.
- Installing a stationary well adjacent to the flume to house water level sensors to ensure stable and reliable readings.
- Mounting the capacitance water level sensor inside the stationary well, enabling continuous measurement of the water level.
- Encasing data logger in a cylindrical, water-resistant casing and its subsequent placement within a secure metal enclosure to safeguard against extreme weather conditions and potential damage.
- Configuring water level sensors and data loggers to collect water level data at specified intervals, typically every 5-30 minutes, for comprehensive monitoring.
- Calibrating the water level sensor regularly to ensure accurate measurements.

This approach facilitates precise monitoring of water levels and flow rates employing HS flumes and water level sensors, thereby offering invaluable data for hydrological assessment, water resource management, and environmental monitoring. There are some salient points which should be kept in mind during the installation of a HS flume for the measurement of spring discharge:

- Proper sizing is the first and foremost step in successful installation of a HS Flume. The size of a HS flume should be carefully decided by considering the minimum flow, average flow and maximum flow of the springs. The intention of this is to ensure that selected HS flume can safely handle the variability of spring discharge throughout the year.

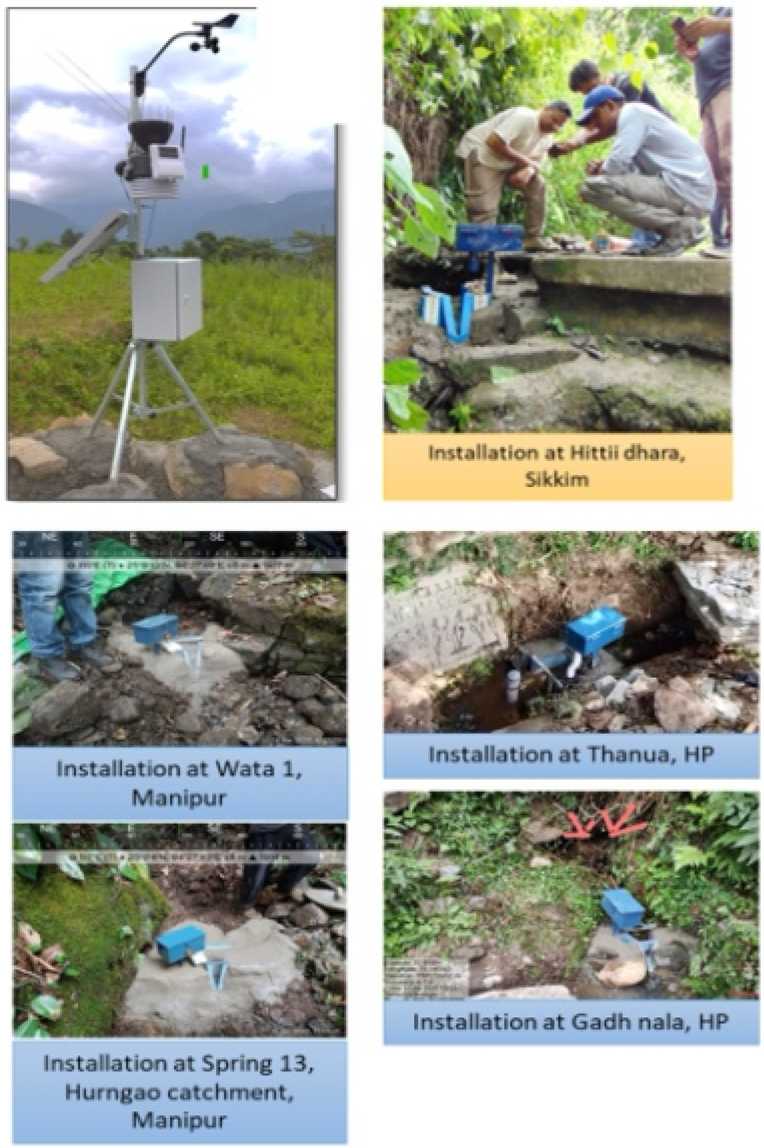


Fig. 4.4 Installation of flumes and AWS

- The upstream condition of the site where flume to be installed should be such that flow entering the flume is smooth, well distributed, and of the proper velocity.
- Any flow changes in the channel should be at least 3-5H_m upstream.
- The channel slope should be 2% or less.
- The flume itself should be level from front-to-back and from side-to-side.
- Flume should be at a sufficient distance to any downstream channel (if exist) to avoid any erosion/scouring from the downstream channel.
- Flumes should be securely anchored to the ground to prevent them from floating or shifting from their designated installation position.

4.3.2 Automatic Weather Station setup

Automatic Weather Station (AWS) for recording meteorological parameters is important to install in the springshed. This involves selection of strategically suitable locations within the springshed. These locations should be devoid of canopy cover and electricity distribution lines while being situated in open spaces to facilitate unhindered exposure to wind, rainfall, and sunlight. This selection is crucial to ensure the collection of representative hydro-meteorological data through the establishment of automatic weather stations. These stations should be capable of measuring essential real-time meteorological parameters including rainfall, temperature, humidity, wind speed, and wind direction.

In AWS, generally, the anemometer is mounted on an open-level terrain at 5m above the ground. In contrast, for the roof-mounted weather stations, the anemometer is mounted at 3m. The temperature and humidity sensors are housed inside a radiation shield, usually 1.8 to 2.0 m above the datum. The effects of radiative heating from roof tiles etc., particularly during the summer months, are also considered. The rain gauge is placed above the radiation shield, approximately 2.0 to 2.3 m above the ground. Where stations are equipped with solar radiation sensors, extraordinary care is taken to assure an unobstructed horizon and to avoid shadowing as much as possible (Fig. 4.4).

(a) **Site Monitoring:** The monitoring stations in the network require regular maintenance which includes a site visit at each station every 3 to 6 months.

Maintenance includes station cleaning, inspection of sensors for their functionality, and replacing batteries, if necessary. A significant focus area pertains to the training and skill enhancement of carefully chosen local para-workers. They are trained to conduct periodic maintenance of instrumented sites and regularly transmit sensed data. This training is a major priority as it contributes to efficient data assessment and quality control. The stewards responsible for individual pilot observatories play a pivotal role in optimizing the economics associated with instrumentation, data processing, and analysis. Their oversight and management can significantly enhance the overall effectiveness of these activities.

(b) **Data collection and analysis:**In the data collection and analysis phase, data and observations are systematically collected and processed to draw meaningful insights and conclusions. This important step involves the precise recording of relevant data, often obtained through field measurements, surveys, or sensor readings. Using the known dimensions and geometry of the HS flume, along with the water level readings from the sensors, the discharge can be calculated. Different types of flumes have their own specific formulas for calculating discharge based on water level measurements. Each type of flume is designed with unique geometric characteristics, which lead to variations in the equations used to determine flow rates. As an example, for 0.6-foot HS flume, discharge is calculated using established empirical formulas:

(c) **Formulas (H in meters)**: Flow (Q) in Liter per Second (lps) is calculated as,

$$Q = -0.01047723 - 0.0220549 \cdot H_m^{0.5} + 17.34926614 \cdot H_m^{1.5} + 360.8771555 \cdot H_m^{2.5} \quad (4.1)$$

where, H_m represents the height or depth in meters.

Discharge table of each type of flume is also provided by the manufacturer, an illustration is given in the Table 4.1 for 0.6 foot HS Flume.

Table 4.1: Discharge table for a 0.6-foot HS flume

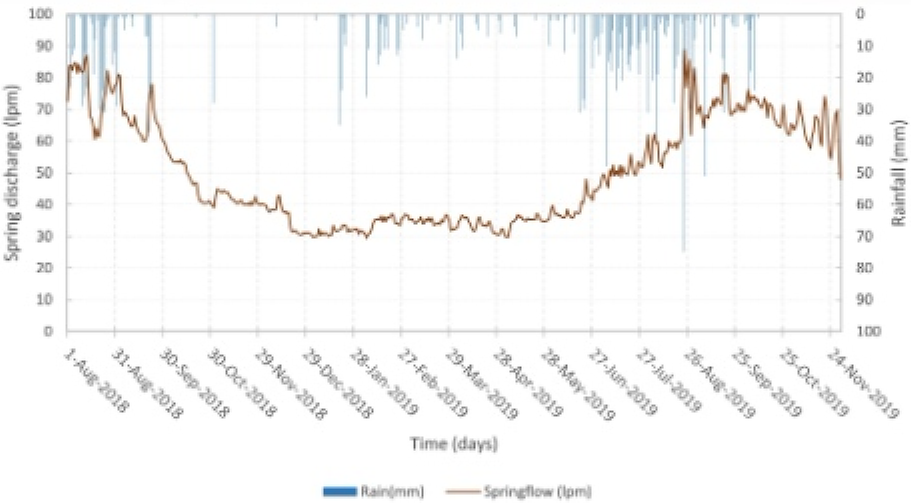
Height of water level above crest (cm)	Discharge (lpm)	Height of water level above crest (cm)	Discharge (lpm)
0.61	0.4	9.75	95.5
1.52	2.3	10.67	116
2.44	3.9	11.89	147.5
3.66	12.6	12.8	173.3

Table 4.1 continued from previous page

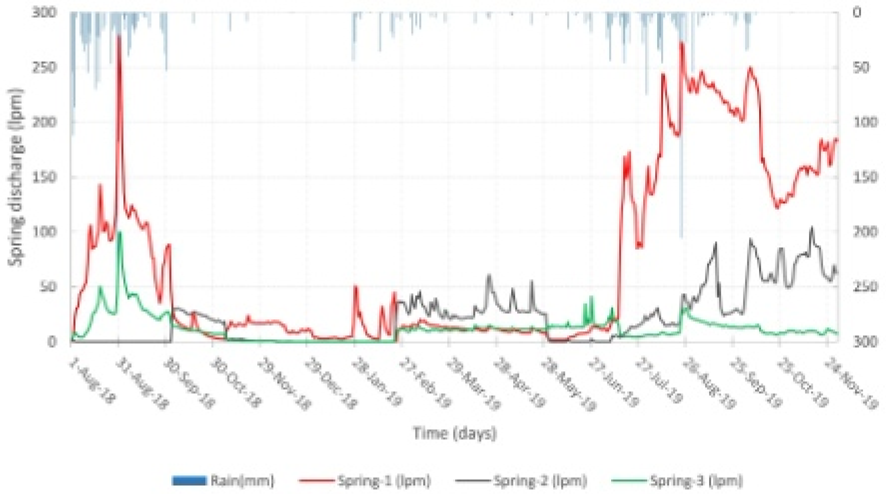
Height of water level above crest (cm)	Discharge (lpm)	Height of water level above crest (cm)	Discharge (lpm)
4.88	22.3	13.41	193.7
5.49	28.2	14.02	214.1
6.71	42.8	15.24	258.3
7.92	61	16.76	319.4
8.84	77.2	17.98	375.5

(d) **Data interpretation:** Figure 4.5 shows the first set of processed data after instrumentation of selected springs. The spring discharge of Shiv Gadhera (Fig. 4.5a) shows a continuous flow of 60-80 *lpm* for the better part of August, the increase in flow can be attributed to rainfall events between 11 to 14 and 21 to 24 the days of August. Discharge may peak in August and subside after the end of the monsoon season. Spring hydrographs of Haraita (Fig. 4.5b) are expected to show a significant recession after the end of monsoon season and analysis of monsoon season data. Discharge in springs is a function of aquifer recharge; so, it is expected to increase in the last phase of monsoon.

Plots of spring discharge with rainfall data at daily time scale can provide the vital information of lag time between rainfall event and spring flow. Such information is immense helpful for extraction of the properties of the aquifer which is actually feeding the spring and subsequently in identification of recharge area of the instrumented spring.



(a) Shiv Gadhera, Almora



(b) Haraita, Pauri Garhwal

Fig. 4.5 Spring hydrographs

Chapter 5

Springshed Management Methodology

5.1 Background

Springshed Management (SSM) is an approach that is based on hydrology, hydrogeology and hydro-sociology. The approach focuses on addressing water security challenges for the areas that depend upon spring discharge. The approach uses strategies that ensures continuous water supply from the springs, prevents /or arrests the top-soil degradation, facilitates better livelihood productivity, and helps to secure or restore ecosystem services. The approach also lays weightage to the involvement of local people/communities and is inclusive of decentralized water governance.

The Himalayas, the Western Ghat & Eastern Ghat regions are confronted with certain water-related issues like:

(a) Heavy and intense rainfall with increased surface run-off during monsoons leading to soil erosion and siltation of water bodies downstream. The catastrophic events like land sliding; avalanches; flash floods, earthquakes, etc. are adding to the crisis; and

(b) Drought like situation during summer season leading to acute scarcity of water for drinking, agriculture, and other activities.

(c) Each of these mountain ranges have their own peculiarities: The Himalayas are spread in a longitudinal fashion wherein the western parts are drier than the eastern parts. The Western and Eastern Ghats show more or less latitudinal spread and runs parallel to the coastlines of Indian Peninsula.

Note: *Apart from these three mountain systems, there are at least 15-20 other smaller highlands, often along the boundaries of major river basins, some of them an extension of the Western and Eastern Ghats, others with their own unique locations such as the Aravalli ranges or the Central Indian Highlands.*

5.2 The concept of a springshed

A springshed is the unit of land area where rainfall recharges and later discharges/or contributes to the spring flow (Fig. 5.1). It is the natural unit for revival and management of springs. Springshed represent a term that describes the socio-hydro-geological unit which connects:

(i) A particular spring or cluster of springs.

(ii) The underlying aquifers from which these springs emerge.

(iii) The watershed(s) that overlie these aquifers springs.

(iv) And the communities that depend upon the integrated system of watersheds on the surface and subsurface aquifers through the use of discharged spring water.

The accumulation and movement of groundwater that feeds a spring water is determined by the underlying geology that is, the nature of rocks, and their composition, texture, structure, and weathering conditions. The point where the spring emerges is based on the relationship of the aquifer to the watershed surface. As defined above, a typical watershed drains water from a ridgeline into the valleys (drainage lines) that converge to a common point – possibly at the confluence of a river, whereas a springshed is a set of watersheds and aquifers that integrate into a system and supply the water to a group of springs (Shrestha et al., 2018).

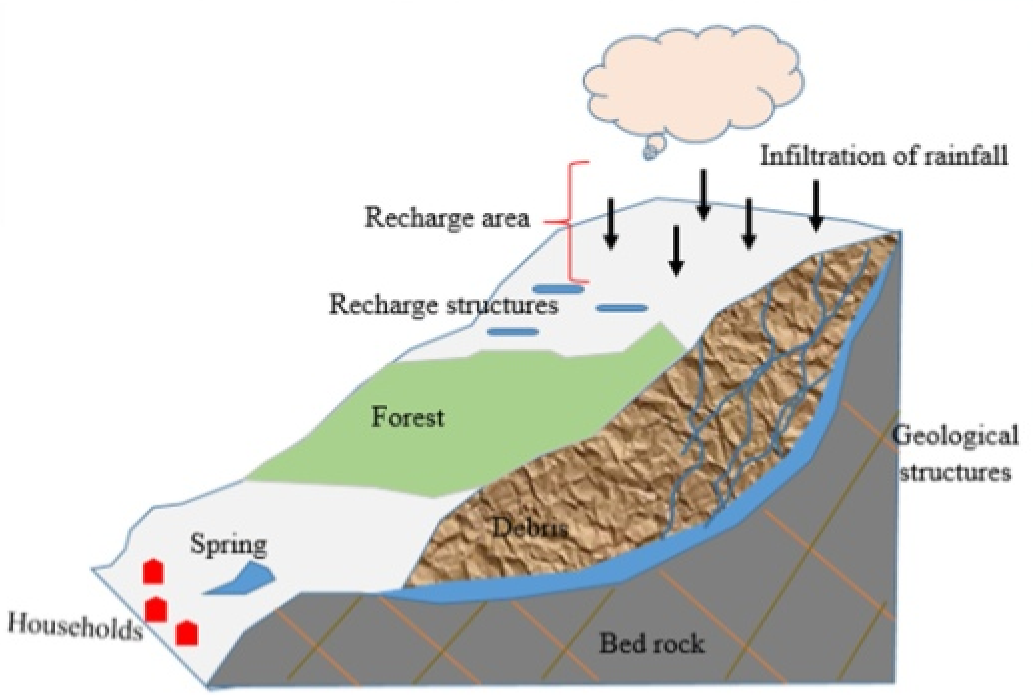


Fig. 5.1 Illustration of springshed

5.3 Springshed Management: a methodology that integrates various disciplines

The concept and practice of SSM has evolved through experience gained from the field during the last two decades.

- Government agencies, academia and research agencies has done significant work in defining the hydro-geology around springs, especially in the Himalayas.
- A nine step methodology was developed for recharging Himalayan springs in 2006 by Central Himalayan Rural Action Group (CHIRAG). The interventions were implemented initially as a project from 2008 in partnership with ACWADAM.
- The approach matured into a more refined, eight step process which was implemented by the Government of Sikkim as a flagship Dhara Vikas Programme. in partnership with PSI and ACWADAM.
- The inputs and experiences from the CSOs and Government agencies from the

Indian Himalayan Region (IHR) were collated and documented as an eight-step protocol by the NITI Aayog (NITI Aayog, 2018).

- Derived from the work carried-out in the field by different agencies working in the Hindu Kush Himalayan region, a methodology of SSM was evolved and published by ICIMOD (Shrestha et al., 2018).

It is recommended that the same methodology be adopted and adapted (to conditions and situations) across the country, for the process of rejuvenation, restoration, revival, conservation, monitoring and management of springs. The adaptation, refinement and improvement should be a function of experiential learning as more and more projects and programmes on SSM are implemented not just in the Himalayan Region but across other regions as well.

SSM is a people-centric approach. It embraces the necessity to involve local people from the springshed areas for the sake of developing a sense of ownership. Noticeably, the recharge zones and their corresponding point of appearance as springs are likely to exist in the same landscape in various permutations and combinations, mainly:

(i) The spring, aquifer and the watershed boundaries are coherent, i.e., a single watershed includes the aquifer and the springs.

(ii) Various springs fed by more than one aquifer emerge in a single watershed.

(iii) The inclined aquifer outcrops in two different watersheds, one being fed by the surface water from a watershed (natural recharge area) and the springs (groundwater discharge) emerging in the other watershed.

(iv) Multiple watersheds are underlain by a complex aquifer system (more than one aquifer) and several clusters of springs.

Spring water, its depletion and contamination are part of the degradation and deterioration of 'common pool resources' or 'commons' in an area or region. It is a socio-hydrological problem in general and a socio-hydro-geological issue in particular and must be perceived and resolved through a process of sociology and hydrogeology together. Engineering techniques must be properly incorporated into this process. Ecosystem considerations must also be carefully understood and embraced. The following are the core components of springshed management:

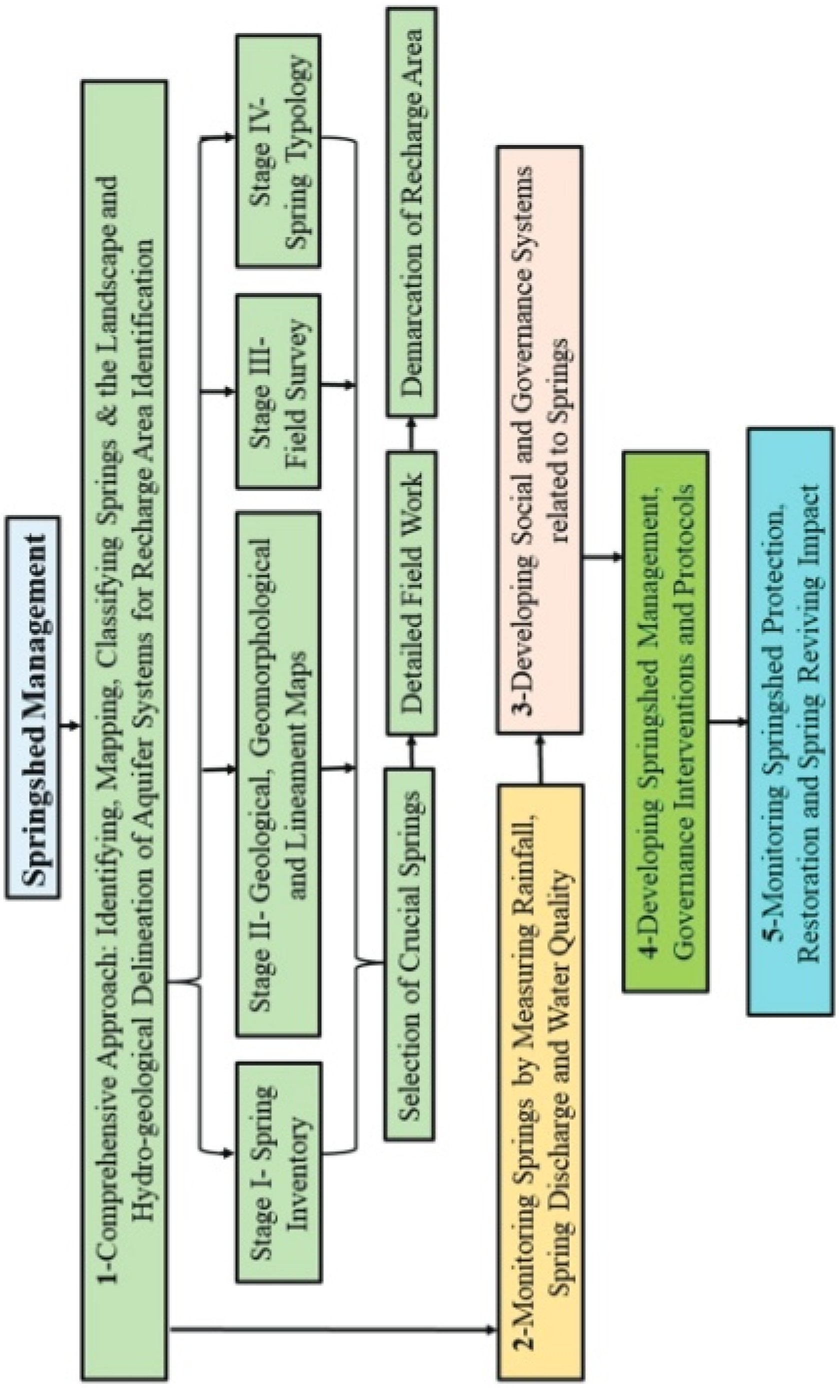


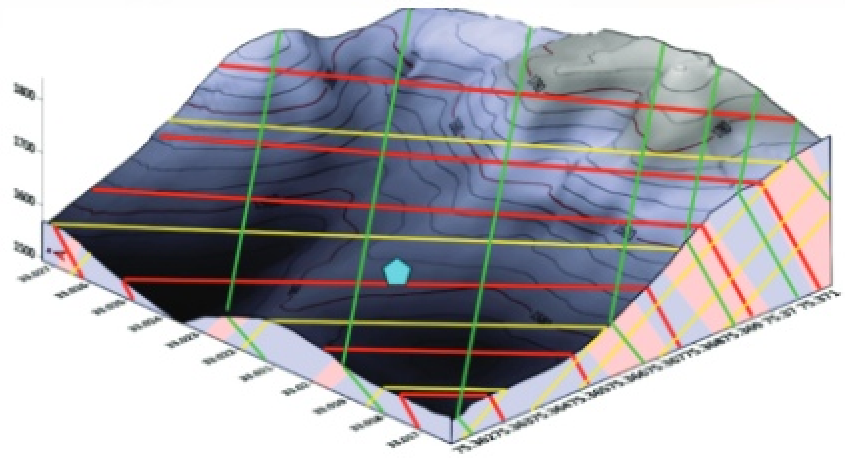
Fig. 5.2 Workflow of steps for springshed management

- Reliable database on springs, type of spring, their number, discharge and quality, etc.
- Information on springshed hydrogeology, springshed conservation and systematic utilization of spring water.
- Water management, rainwater harvesting and Managed Aquifer Recharge.
- Conservation, afforestation and reforestation.
- Soil and land management for the restriction and reduction in soil erosion.
- Livestock management, Pasture (Fodder) development.
- Agricultural development includes Agro-forestry practices, Organic farming and precision agriculture to increase income.
- Rural energy management to reduce dependency on the forest cover for firewood.
- Community development and increased participation for sustainability and developing a sense of ownership.

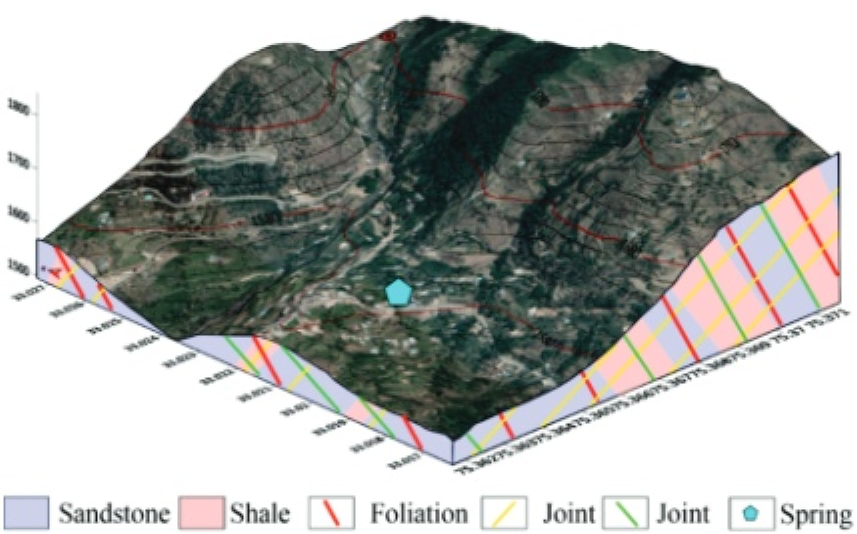
The methodology of SSM must include the following key steps (Fig. 5.2), based on a scientific approach involving hydro-geological investigations, planning, design, implementation and impact measurement. This must become a standard operating procedure that allows for more detailed, site-specific guidelines on SSM for different locations.

5.3.1 Comprehensive Approach: identifying, mapping, classifying Springs and landscape and Hydrogeological delineation of aquifer systems for recharge area identification

To develop springshed, the first crucial step is identifying and mapping springs in a region through a systematic inventory. It is to be followed by classifying each spring to understand its nature and origin, creating a geotagged spring inventory. Basic details like geology, hydrology, slope, and rainfall are to be considered while mapping. Importantly, geotag all springs, not just those used by communities, and update the inventory regularly due to potential landscape changes. Referring to secondary information like regional mapping is advisable. This process is vital for delineating springshed and planning interventions, especially for recharge measures. Protecting recharge areas and their catchment zones from natural and human-induced factors is crucial. This step includes developing a conceptual model of the springshed (Fig. 5.3a) and overlaying different elements on a map or Google Earth image (Fig. 5.3b).



(a) 3D topography of springshed using DEM



(b) 3D topography of springshed overland by google earth image

Fig. 5.3 Conceptual 3D model of the springshed

The comprehensive approach shall include the following stage and steps for execution as follows:

5.3. Springshed Management: a methodology that integrates various disciplines

Stage-I

- **Creation of a springs inventory:** An inventory of springs within the designated area will document the locations and characteristics of each spring, providing a valuable resource for future analyses and management efforts.

Stage-II

- **Plotting spring locations on the base map using Digital Elevation Model (DEM):** The data for spring locations should be mapped onto the base map, specifically the DEM of the area, providing a spatial context for understanding the distribution of springs.
- **Preparation of geological and lineament maps utilizing existing literature and online resources:** The geological map for the area could be generated by synthesizing information from existing literature and leveraging available online resources, such as BHUVAN, BHUKOSH, to enhance the understanding of geological features.
- **Generation of geomorphological map**: A geomorphological map for the area will provide insights into the surface features and landforms, contributing to a more comprehensive understanding of the area's landscape.

Stage-III

- **Conducting geological reconnaissance survey:** A comprehensive geological reconnaissance survey is imperative for the entire area to gather crucial insights into the geological features and composition.
- **Integration of thematic layers, including geology, geomorphology, lineaments, and spring locations:** To enhance the understanding of the springshed of the area, the integration of various thematic layers such as the geology (map, cross section, a 3-D block diagram), geomorphology, lineaments, and spring locations is essential. This holistic approach ensures a cohesive analysis of the diverse factors influencing the region.

Stage-IV

- **Comprehensive typology assessment of vulnerable springs using field and secondary data:** The determination of vulnerable springs' typology involves the utilization of both field and secondary data, ensuring a thorough and integrated analysis.

Stage-V

- **Fieldwork for comprehensive geological data collection:** A field visit shall be conducted to gather in-depth geological data. During this survey, detailed information on the geological characteristics of the area will systematically be collected to enhance the understanding and supplement subsequent analyses or studies.

Stage-VII

- **Identification of recharge areas for vital springs:** Recharge areas for critical springs should be determined based on factors such as geology, lithology, geomorphology, altitude, slope, aspect, meteorological conditions, land use, land cover, and anthropogenic influences in the region.
- **Development of a conceptual hydrogeological model for key springs:** Formulating a conceptual hydrogeological model is essential for understanding the dynamics of crucial springs. This model should integrate key factors like geological features, hydrological processes, and groundwater flow, providing a comprehensive understanding of the spring's hydrogeological context.
- **Recommendation of feasible recharge interventions:** Proposing plausible interventions for recharge is crucial. This involves suggesting practical measures to enhance the recharge of vital springs, considering the identified factors and the conceptual hydrogeological model. The aim is to ensure sustainable water resources and ecosystem health in the region.

5.3.2 Monitoring springs by measuring rainfall, spring discharge and water quality

Rain gauging along with spring discharge and quality of spring water should be measured and monitored regularly to understand the quality and amount available from a specific spring or a set of springs. CGWB uses a protocol to monitor groundwater regime four times a year and water quality once in a year. In the same way, a few springs throughout the country may be taken up for regular monitoring. Water quality samples from springs may be collected and analyzed twice a year. Community Resource Persons (CRPs) can be trained to undertake such measurements on a regular basis during the process of springshed management, while available secondary information can also be referred to.

5.3.3 Developing social and governance systems related to springs

A socio-economic survey of community-established water-use patterns related to springs, their social and economic implications and the institutions of governance of spring water, rights to spring water, traditions and customs must be undertaken. Reasons for the drying up of springs, water distribution from springs and factors related to competition, contestation and conflict must be carefully curated from such surveys. Often, such aspects are ignored during an oversimplified process of working only on the supply-improvement from springs.

5.3.4 Developing springshed management, governance interventions and protocols

This includes two elements that are closely integrated. The hydrogeological mapping helps identify the natural recharge zones in the springshed. However, the slopes, the land use & land cover, soil types should determine the nature of recharge interventions in such areas. Proposed interventions may be biological or physical in the form of afforestation, planning of grasses, bunds, trenches, ponds etc. While designing and implementing such interventions, care must be exercised that the interventions themselves are safe in a manner that they do not impose excessive hydraulic loads on the surface that may lead to unwanted consequences such as landslips and slope failures.

Other elements may include aspects of changing social behavior for social (fencing) to reduce the impact of human activities and some natural phenomena detrimental to spring water discharge and quality. Protection of certain areas from grazing, forest fires or even impeding infrastructure is part of these interventions and requires more of social mobilization and facilitation and less of specific physical measures. Community decisions around such activities must be ratified through the gram sabhas or village councils as clear aspects of institutionalizing springshed management. Such decisions have a constitutional and democratic angle to the process. Operation and maintenance activities of physical and biological interventions for the long run also have to be provisioned as part of the SSM and governance process.

5.3.5 Monitoring springshed protection, restoration and spring reviving impact

Measuring the hydro-social impact of SSM is important. The measurement of critical parameters like spring discharge and quality along with social aspects like equity in access and the improvement in the quantum and quality of such access must be recorded at least for a couple of years after the SSM project has concluded. On the whole, impact should be measured around whether availability of water has improved and whether this availability is representative of improved groundwater stocks in the aquifer, improved systems of spring-water supply and distribution and improvement in demand of spring-water, if any. Aspects of water use efficiency, equitability in access and distribution and the overall sustainability of springs that also includes provisioning part of the spring discharge as an ecosystem service must be understood.

The protection and restoration of the springshed's ecological integrity is crucial for springshed management. This involves preserving the recharge areas, which are often forests, through measures such as afforestation, reforestation, and preventing encroachment. Restoring degraded land through soil and water conservation practices, including contour bunding, check dams, and terracing helps enhance water retention and recharge, promoting the revival of drying springs. Measuring the impact of spring revival activities by analyzing to assess the impacts of intervention activities in the recharge area.

5.4 Conclusion

While the above steps form the preliminary SOP for SSM activities (detailed out in a variety of documents and documentation by various agencies), it is important to also flag the following key aspects which this process must integrate.

- An institutional mechanism of roles and responsibilities during a SSM process, while also remembering that the process integrates principles, people and processes while getting to a policy framework through partnerships and collaborations.
- The different, often overlapping roles of central government agencies (CGWB, GSI, NIH, MoEF-GBPNIHE, IIT-Roorkee), State Agencies and NGOs shall be promoted. It must be further mentioned here as a word of caution that compartmentalizing roles into silos may defeat the purpose behind the process

and healthy partnerships can evolve through a model of co-operation on the ground.

- Integrating the various work components under one umbrella, through a national Programme on SSM.
- It would be prudent to begin with model projects (or lighthouse projects) for illustrating the concept of Integrated Springwater Management across the entire typology of springshed across different regions of India.

Chapter 6

Spring Water Quality Monitoring and Analysis

6.1 Background

Water quality is a major concern in the 21st century, alongside the need to provide an adequate amount of water to every household. Springs are the common sources of water for communities in the mountainous regions of the country. During 1961–2011, the Himalayan population grew by 250% with an annual growth rate of 3.3%, which is three times the world average growth rate. This rapid growth led to accelerated urbanization eventually causing the damage to recharge zones and degradation of water quality of the springs. Therefore, there is an urgent need to measure and monitor the water quality of local springs to ensure the prescribed quality on a regular and long-term basis to ensure improvement in living standard of rural communities.

This chapter aims to guide personnel on correctly monitoring and analyzing India's spring water. The subsequent sections outline protocols for collecting spring water samples, their analysis, data management, interpretation, reporting and data sharing. These standard operating procedures are subject to modification when necessary to adapt to diverse site conditions, equipment constraints, or procedural limitations. Field personnel must document the specific procedures implemented consistently.

6.2 Flowchart for spring water quality monitoring

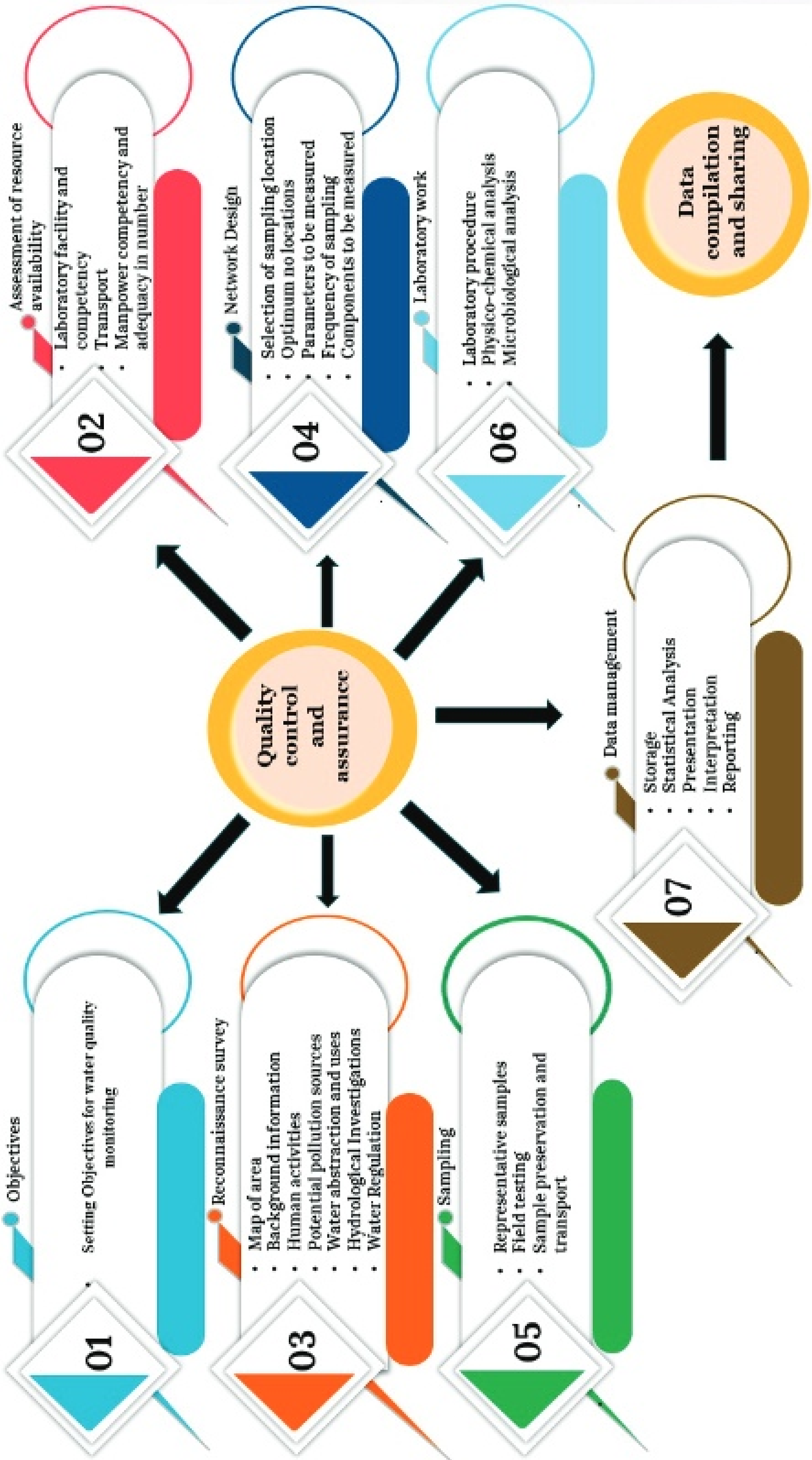
Step by step guidelines for spring water quality monitoring is illustrated in Fig. 6.1 (Adapted from CPCB, 2007). Before developing any water quality monitoring program, it is of utmost importance to thoroughly comprehend the monitoring objectives, methodology, quality assurance, data validation, and other relevant aspects. Once the monitoring objectives have been defined, evaluating the resources at hand for conducting the monitoring becomes essential. Before the planning of a water quality monitoring program, it is crucial to ensure the availability of the sampling equipment, transportation for collecting samples, laboratory facilities, sufficient and adequately trained personnel, equipment, glassware, instruments, chemicals, and other tools for the analysis of the required parameters, financial resources for the maintenance and operation of the laboratory. Furthermore, during the planning phase, conducting a preliminary survey of the spring is imperative. This survey aims to identify all potential sources of spring water, any discharge points that may introduce pollutants, and the various purposes and withdrawals of water from the spring. Furthermore, this survey should collect additional data, including geographical features, topography, climate, weather patterns, hydrology, hydrogeology, land use, urban development, industrial activity, and agricultural practices, including upstream areas. The survey provides an overall understanding of the geographical location of the spring and other nearby water bodies which need to be monitored. It also assesses the susceptibility of the spring to various human influences, aiding in determining the suitable locations and the required number of sampling sites. For detailed information of steps 1-7, please refer to CPCB guidelines for water quality monitoring (Board, 2007).

6.3 Spring water sampling network selection

Spring water monitoring framework should be categorized as follows:

(i) **Baseline monitoring:** This refers to an on-going program of surveys that is systematically conducted to provide a series of observations within a defined period.

(ii) **Trend monitoring:** Areas which show anomalous concentration of any form of contaminants more than the permissible limit should be monitored regularly and termed as trend monitoring wells. This involves continuous surveillance that is carried out to achieve a set of predetermined objectives.



(Source: Adapted from CPCB 2007)

Fig. 6.1 Steps for water quality monitoring

(iii) **Special purpose monitoring:** Monitoring station where a pollutant is mixed with water. Special focus should be taken up in areas where new geogenic contamination in spring water has been reported or anthropogenic influence has changed the water quality.

6.4 Spring water sampling

When designing the spring sampling network, it's crucial to consider the ideal number of sampling locations, the frequency of sampling, and the necessary parameters to fulfill the desired objectives. If variations are large in a short duration of time, a larger frequency is required to cover such variations. On the other hand, if there is no significant variation in water quality, frequent collection of samples is not required. Table 6.1 illustrates the frequency of sampling for each type of stations. Furthermore, at least one day before sampling, make sure that all the arrangements are made as per the check list. A list of items which should be checked before starting on a sampling mission is given in Table 6.2.

Table 6.1: Parameters and frequency of monitoring

Type of Station	Frequency	Parameters
Baseline monitoring	**Perennial springs and Seasonal springs:** *Two to four times a year for the first ten years (at equal spacing) during the flow followed by sampling at an interval of three years.*	• **General Physico-chemical parameters:** Colour, Odour, Temperature, *pH*, Electrical Conductivity, Dissolved Oxygen, Oxidation Reduction Potential, Turbidity, Total Dissolved Solids, Ammoniacal Nitrogen, Nitrite, Nitrate, Total Phosphate, Biological Oxygen Demand, Chemical Oxygen Demand, Total Organic Carbon, Total Nitrogen, Sodium, Potassium, Calcium, Magnesium, Carbonate, Bicarbonate, Chloride, Sulfate, Fluoride, Boron, and any other location specific parameter. • **Microbiological:** Total Coliform and fecal Coliform • **Pesticides:** Alpha Benzenehexachloride (BHC), Beta BHC, Gama BHC (Lindane), OP-Dichlorodiphenyltrichloroethane (OP-DDT), PP-DDT, Alpha endosulphan, Beta endosulphan, Aldrin, Dieldrin, Carbaryl (carbamate), Malathion, Methyl parathion, Anilophos, Chloropyriphos , and any other as per regional need based. One time analysis of these parameters are necessary, further analysis will be based on the observations. • **Toxic metals:** Arsenic, Cadmium, Mercury, Zinc, Chromium, Lead, Nickel, Iron. The parameters may be selected based on their possibility to presence in the area. Frequency of analysis will be once a year.

Table 6.1 continued from previous page

Type of Station	Frequency	Parameters
Trend or Special purpose monitoring	Two to four times every year	• **Pre-monsoon & Post-monsoon Collection and Analysis:** Analyse parameters as listed for baseline monitoring. • **Other months:** Colour, odour, temperature,pH, Electrical Conductivity, Dissolved Oxygen and Turbidity, Ammoniacal Nitrogen, Nitrite, Nitrate, Total Phosphate, Biological Oxygen Demand, Chemical Oxygen Demand, Total Organic Carbon, Total Nitrogen, Chloride, Total and fecal Coliforms.

Table 6.2: Check list for the field visit

Items
✓ Itinerary for the trip (route, digital map of the springs to be covered, start and return time)
✓ Sample preservatives (e.g., acid solutions)
✓ Personnel and sample transport arrangement
✓ Graduated bucket for measurement of spring discharge
✓ Area map, sampling site location map (digital as well as hard copy), GPS device
✓ Thermometer, Tissue paper
✓ Other field measurement kit, such as portable pH, TDS/EC, DO & OPR meter, etc.
✓ Soap, Towel, Match box
✓ Icebox filled with ice or icepacks or ice for preserving the samples
✓ Spirit lamp/Torch
✓ Sample containers for general, bacteriological, heavy metals, etc.
✓ Drinking water
✓ Knife, First-aid box
✓ Gloves and eye protection
✓ Rope, labels for sample containers
✓ Field notebook and sample identification form, pen / pencil / marker water sampler

6.4.1 General guidelines for spring sampling

(a) The sample identification form comprising the 'sample collection and submission' form should be filled for each sampling occasion at a monitoring station (Table 6.3).

(b) Each sample should be labelled properly as per the protocols. Label the sample container properly, preferably by attaching an appropriately inscribed tag or label. Alternatively, the bottle can be labeled directly with a water-proof marker.

6.4. Spring water sampling

Information on the sample container or the tag should include:

- Sample code number (identifying location as mentioned in the sample description form)
- Date and time of sampling
- Source and type of sample
- Pre-treatment or preservation carried out on the sample
- Any special notes for the analyst

Following the above guidelines some physical parameters of spring water will undergo onsite testing, while samples will be collected for subsequent laboratory analysis (Fig. 6.2a & Fig. 6.2b).

(a) Onsite monitoring of some physical parameters of spring water

(b) Field collection of spring water samples for in-depth analysis of various parameters in the laboratory

Fig. 6.2 Spring water collection and in-situ analysis

Table 6.3: Sample collection form

Particulars	Sample Code	SP 01	HP 01	NL 01
Details of spring water monitoring stations	Source of sample	Spring	Hand pump	Nallah
	State/UT	Himachal Pradesh	Himachal Pradesh	Himachal Pradesh
	District	Chamba	Chamba	Chamba
	Block/Taluka	Salooni	Salooni	Salooni
	Village	Sherpur	Sherpur	Sherpur
	Lat	32.582°	32.584°	32.581°
	Long	75.952°	75.957°	75.956°
	Altitude	667 m	725 m	695 m
	Date	15.02.2023 (10:15 AM)	15.02.2023 (02:00 PM)	15.02.2023 (05:30 PM)
	Discharge	10.6 lpm	25.6 lpm	NM*
	Usage	Drinking/ Domestic	Drinking/ Domestic	Irrigation
Field parameters	Temperature	18.7°C	2.6°C	7.9°C
	pH	7.9	7.2	8.2
	EC	$432 \mu S/cm$	$595 \mu S/cm$	$225 \mu S/cm$
	DO	$5.2 mg/l$	$2.6 mg/l$	$7.9 mg/l$
	ORP	125 mV	0	90 mV
Sample collected	B (A/B)†	Yes	Yes	Yes
	B (Major C/A)‡	Yes	Yes	Yes
	HM§	Yes	Yes	Yes
	Isotope (^{18}O, ^{2}H)	Yes	Yes	Yes
	Tritium (^{3}H)	Yes	Yes	Yes
	Bacteriological	Yes	Yes	Yes

*Not measured
†Basic (Alkalinity/Bicarbonate)
‡Basic (Major Cation/anions)
§Heavy metal

6.4.2 Sample preservation and transport

Preserve the collected samples as specified in Tables 6.4. Upon reaching the laboratory, samples should be transferred as soon as possible to a refrigerator.

Table 6.4: Preservation and volume of sample required

Parameters	Containers used for sampling	Volume of sample	Preservation
Basic (Alkalinity/ Bicarbonate)	Polyethylene (PE)	$60ml/125ml$	-
Basic (Major cation/ anions)	Polyethylene (PE)	$60ml$	-
Heavy metal	Polyethylene (PE)	$60ml/500ml$	HNO_3,$pH<2$
Bacteriological	Glass, PE autoclavable	$125ml$	4°C, Dark
Isotope ($O\&H$)	Polyethylene (PE)	$60ml$	-
Pesticides	Glass, Teflon	$1000ml$	4°C, Dark

6.5 Laboratory work

Work assignments and analysis are to be followed as per quality manual, laboratory procedure manual, work instructions, SOP for water analysis of each laboratory. The procedure that should be followed before going to the field and in the field is illustrated in Fig. 6.3. Various parameters comprising physical, chemical and bacteriological are required to analyze for understanding the type of water quality of spring, type of geological formation in the springshed, pollution from various sources and determine any remedial measures to improve the spring water quality, if desired. Various methods, associated protocols and specific instruments to be used are summarized in Table 6.5.

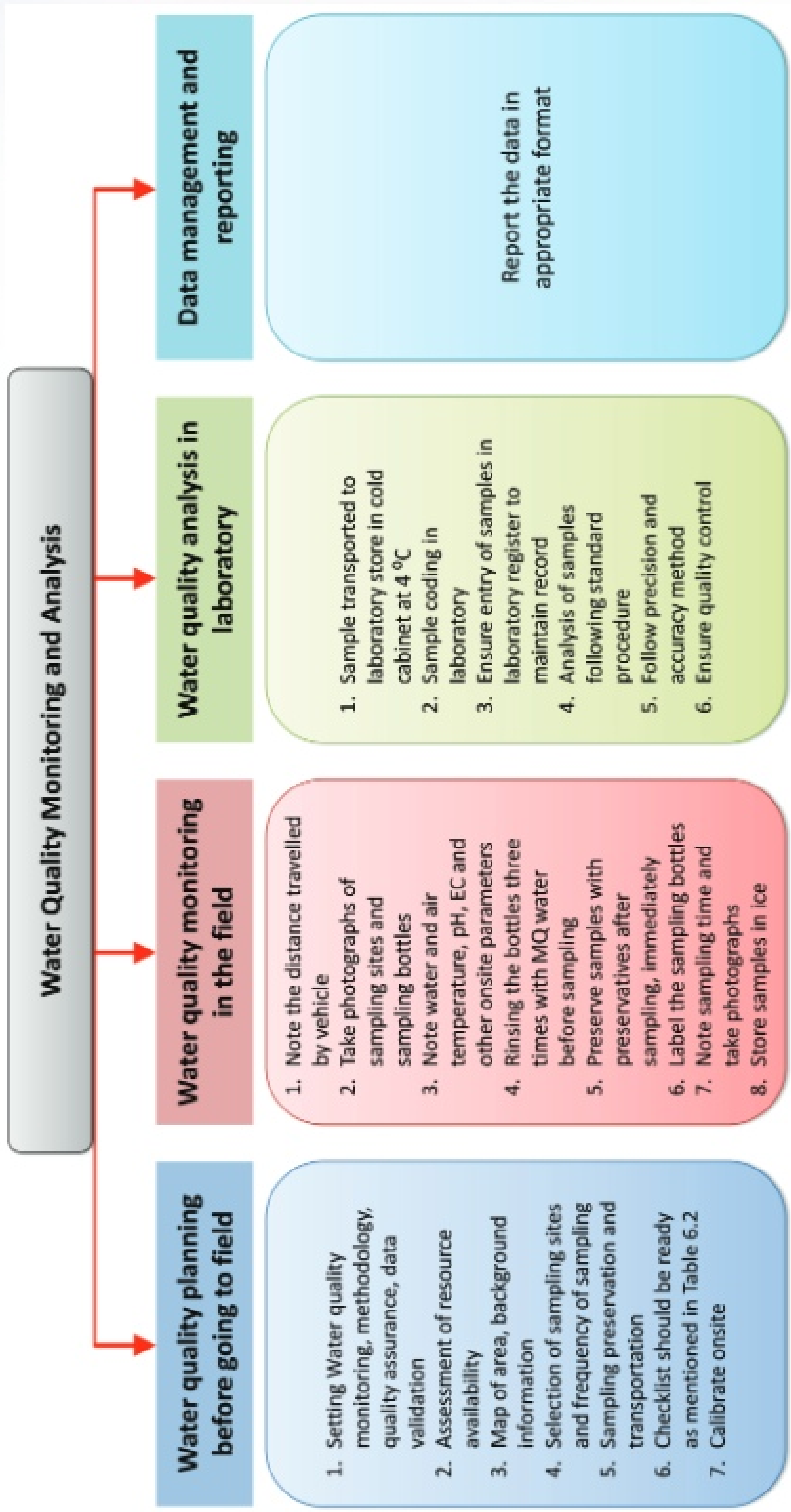


Fig. 6.3 Showing the procedure to be followed during sampling and analysis of water samples

Table 6.5: Standards protocol and methods for water quality analysis (APHA)

Parameters	Instruments	Protocol
Physical parameters (pH, temp., EC, TDS, DO, Colour, Odour, etc.)	Portable pre-calibrated measuring kits	• The probes should be washed with ultra-pure water prior and post usage for analyzing the sample • Prior to the use, the probes should be calibrated using the standard solutions (Certified Reference Material i.e., CRM)
Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^-), Alkalinity	Titration through Titer top $25ml$ using 0.2N concentrated H_2SO_4 solution	• Unfiltered water samples will be used for the analysis • Preparation of 0.2 N H_2SO_4 solution should be used • **Standards:** 2-3 drops of Phenolphthalein for CO_3^{2-} and Bromocresol/methyl orange for HCO_3^- • The acid consumed during titration will be used for the calculation of CO_3^{2-} and HCO_3^- concentration in water. Meanwhile alkalinity can also be calculated from this method.

Table 6.5 continued from previous page

Parameters	Instruments	Protocol
Major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, NO_2^-, NO_3^-, SO_4^-, PO_4^{3-})	Ion Chromatograph (IC)	**Sample requirement:** • Filtered water samples with 0.45 micron will be used for the analysis • Prior to the use, the instrument should be calibrated using the standard solutions (CRM) e.g., MERCK, Thermo scientific • Standards CRM of 1 *ppm*, 2 *ppm*, 5 *ppm*, 10 *ppm*, etc. should be run to calibrate the instrument • Standards and repeats of samples should be run in regular interval between the analysis (e.g., after every 10-15 samples) to check and maintain the accuracy of the results
Trace metals/ elements	Inductively coupled plasma mass spectrometry (ICP-MS)/ Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES)/Atomic Absorption Spectrophometer (AAS)	• Prior to the use, the instrument should be calibrated using the standard solutions • Samples should be acidified with conc. HNO_3 (0.5 ml/100 ml sample) in the field itself to reduce its pH to < 2.0

Table 6.5 continued from previous page

Parameters	Instruments	Protocol
Bacteriological analysis (Total coliform and E. coliform)	Colilert method	**Sample requirement:** • 250 ml sample to be collected in wide mouth autoclaved bottle and stored at a temperature of 4°C before analysis • Some space should be left for aeration in the bottle
Pesticides residue	Liquid-Liquid Extraction Gas Chromatography (LLE GC), Gas Chromatography-Mass Spectrometry (GC/MS) technique	• Prepare the samples for extraction according to established protocols. • Use appropriate solvents and techniques to extract the pesticides from the sample matrix. • Inject the prepared samples into the chromatograph (GC or LC) for separation. • Detect and quantify pesticides based on their retention times (GC) or response in the mass spectrometer (MS).
Isotope analysis (Stable)	Isotopic Ratio Mass Spectrometer (IRMS)	• A 300 μl sample to be analyzed via IRMS for $\delta^2 H$ and $\delta^{18} O$. • Calibration to be done with the primary standards (VSMOW, GISP, SLAP). Secondary internal standards should also be measured with each sample bracket set up for calibration and monitoring. • Isotope ratios to be represented inδnotation in permil (‰) relative to VSMOW.

6.6 Data management

(a) A recommended format for recording data should be given. It includes all parameters, except heavy metals and trace organics which may be analysed in the water quality monitoring programme.

(b) Record of analyses for heavy metals and trace organics, which would be performed on a limited number of samples, should be kept separately in a similar format.

6.7 Quality Assurance (QA)/Quality Control (QC)

The QA/QC programme for a laboratory should be based on their Quality manual that should contain a set of operating principles, written down and agreed upon by the organisation, delineating specific functions and responsibilities of each person involved and the chain of command. Various salient features are given in the Fig. 6.4, which are important for quality assurance of any water quality lab. Rigorous QA/QC should be implemented during step 5 and step 6 of Fig. 6.1.

Fig. 6.4 Various salient points for QA/QC of any water quality lab

6.8 Spring water quality data analysis for hydrogeological processes

Chemical processes within a geological framework are depicted as 'hydrochemical facies'. These facies play a crucial role in examining the distinctive chemical composition of water within hydrological systems. Varied facies found within the same group of geological formations result from groundwater flow patterns within the aquifer system and the influence of local recharge. The various facies are closely associated with the region's geology, and hydrogeological factors influence their distribution. The chemical processes and the evolution of the groundwater in the aquifers due to the residence and the flow may be evaluated using the hydrochemical facies. This can be well interpreted by drawing the Hill Piper plot and Chadha diagram.

(a) **Piper plots:**
A trilinear diagram, often called a Piper or Hill diagram, is employed to identify hydrochemical facies, as illustrated in Fig. 6.5. Piper diagrams bring together anion and cation triangles that share a common baseline. The adjacent sides of these two triangles are oriented at a 60°angle from each other. A diamond shape, positioned between the triangles, is utilized to replot the chemical analyses. Placing a water sample's analysis on a Piper plot can provide valuable insights into the likely origin of spring's water. Piper plots assist in characterizing water type, recognizing precipitation effects, assessing mixing, and understanding ion exchange processes within aquifer geochemistry. Piper diagrams help to categorize different water types based on different hydrogeochemical facies:

- **Calcium-bicarbonate** ($Ca^{2+} - HCO_3^-$) **facies:** Typically associated with groundwater influenced by carbonate-rich rocks.
- **Sodium-chloride** ($Na^+ - Cl^-$) **facies:**Common in areas where seawater intrusion occurs or where the influence of marine salts is significant. It is characterized by elevated sodium and chloride concentrations.
- **Sodium-sulphate** ($Na^+ - SO_4^{2-}$) **facies:** Found in areas with evaporite deposits or where the dissolution of sulfate minerals influences the water chemistry. It often shows elevated sodium and sulfate levels.
- **Mixed facies:** These facies represent a combination of multiple hydrochemical processes and sources, leading to more complex water chemistry.

The concept of hydrochemical facies is based on the understanding that different geological, hydrological, and geochemical processes influence the com-

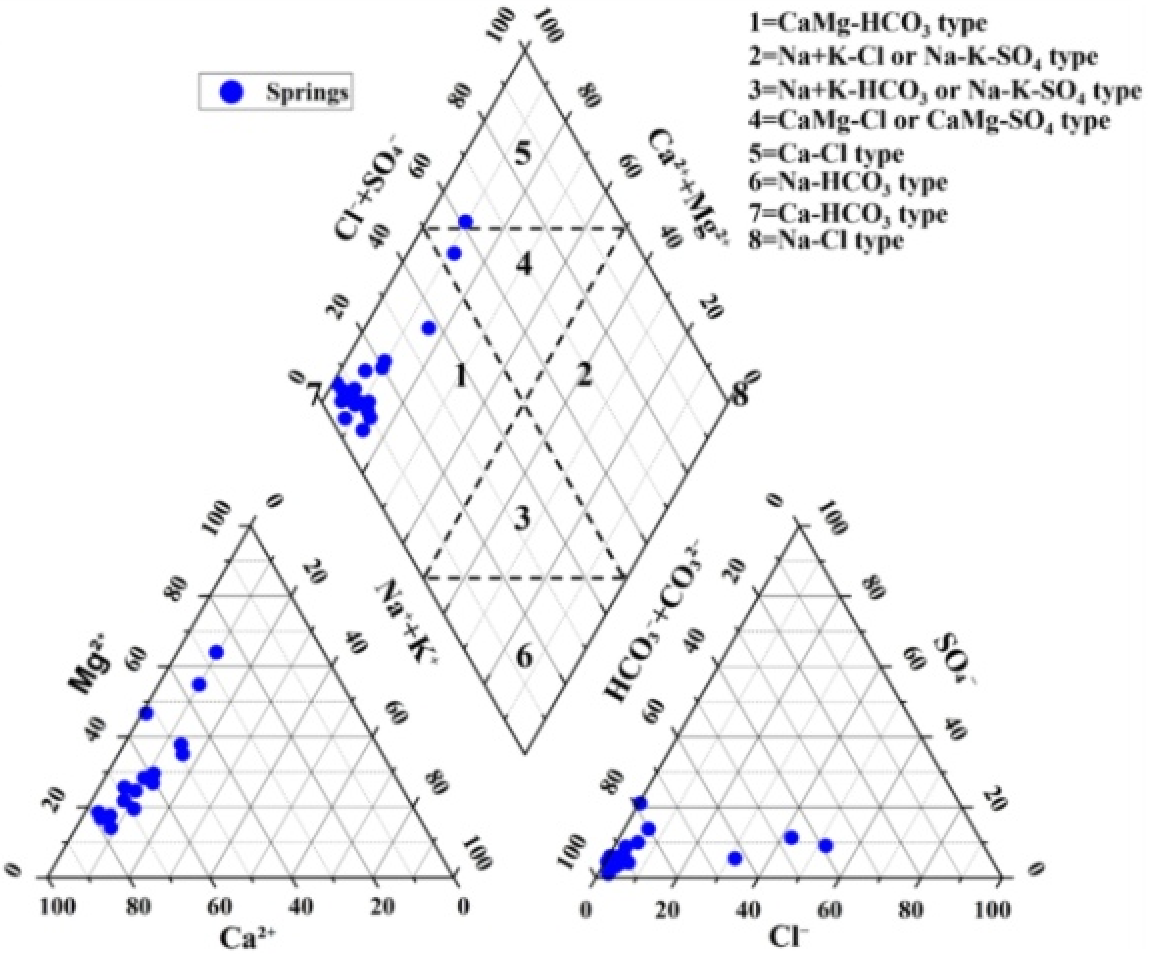


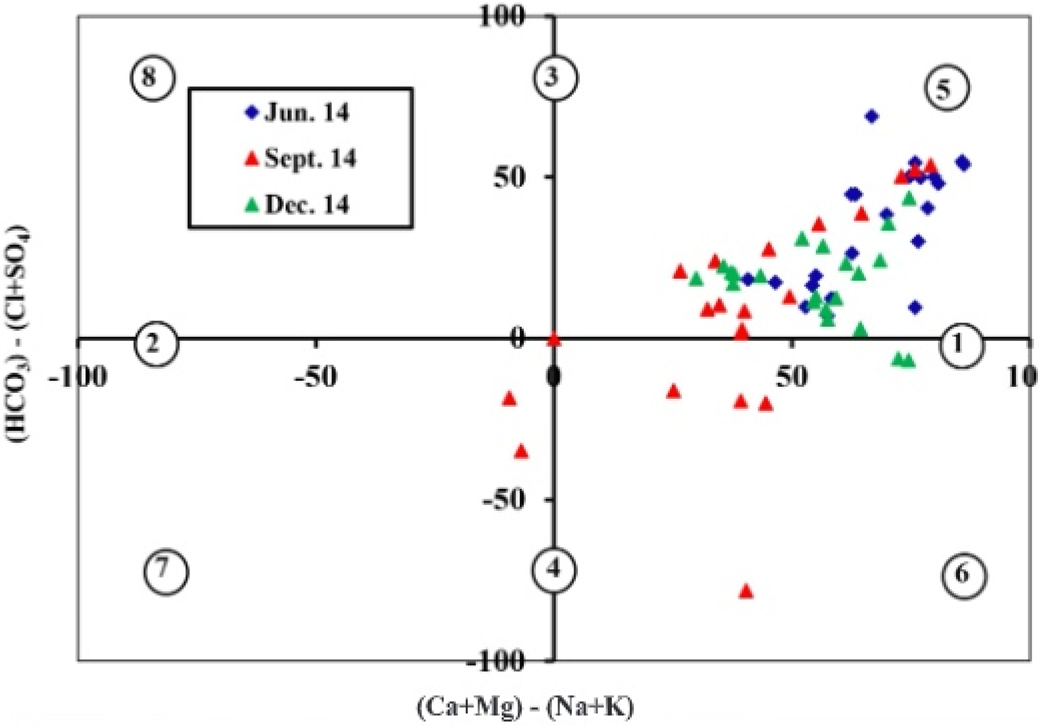
Fig. 6.5 Piper trilinear diagram representing the hydrogeochemical facies of spring water

position of water. These processes can include weathering of minerals, ion exchange, precipitation/dissolution reactions, evaporation, mixing of waters from different sources, and anthropogenic activities. A graphical representation of hydrogeochemical facies present in water samples is presented in Fig. 6.5. The majority of samples plot at the corner of diamond, suggesting $CaHCO_3$ and $CaMg$-HCO_3 type of hydrochemical facies. Apart from that one sample each showed Ca-Cl type and $CaMg$-Cl type of facies for spring water samples. The $CaHCO_3$ and $CaMg$–HCO_3 water types indicate young recharging water of springs. The hydrochemical facies also suggests the significant contribution of carbonate dissolution in contributing to the ionic composition of the springs.

(b) **Chadha Diagram:**
An alternative method for assessing groundwater facies was introduced as a modification of Piper Diagram by Dr. D.K. Chadha, the former Chairman of CGWB (Chadha, 1999). This adaptation simplifies the original Piper plot, and the classification of hydrogeochemical facies is then determined based on the information presented in the Chadha diagram (Fig. 6.6). In this modified diagram, the X-axis represents the difference in milli-equivalent percentages of alkaline earth elements (the sum of Ca^{2+} and Mg^{2+}) and alkali metals (the sum of Na^{+} and K^{+}), while the Y-axis represents the difference in milli-equivalent percentages of weak acidic anions ($CO_3^{2-} + HCO_3^{-}$) and strong acidic anions ($Cl^{-} + SO_4^{2-}$). Each water sample is plotted within one of the four possible sub-fields. The diagram is divided into eight blocks, each representing a distinct water type.

6.9 Hydrochemistry and sources of ions in spring water

The chemical composition of natural water depends on many factors which includes chemistry of atmospheric precipitation, mineralogy of the rocks encountered along the flow path, residence time, topography, and climate. Hence, each spring water has its own physical characteristics and chemical properties that are defined by a unique combination of these factors.



1	Alkaline earths exceed alkali metals	$(Ca^{2+}+Mg^{2+} > Na^{+}+K^{+})$
2	Alkali metals exceed alkaline earths	$(Na^{+}+K^{+} > Ca^{2+}+Mg^{2+})$
3	Weak acidic anions exceed strong acidic anion	$(CO_3^{2-}+HCO_3^{-} > Cl^{-} + SO_4^{2-})$
4	Strong acidic anions exceed weak acidic anions	$(Cl^{-} + SO_4^{2-} > CO_3^{2-}+HCO_3^{-})$
5	Alkaline earths and weak acidic anions exceed both Alkali metals and strong acidic anions	$(Ca^{2+}+Mg^{2+}) + CO_3^{2-}+HCO_3^{-}) > (Na^{+} +K^{+}) + (Cl^{-}+SO_4^{2-})$
6	Alkaline earths exceed alkali metals, and strong acidic anions exceed weak acidic anions	$(Ca^{2+}+Mg^{2+}) > (Na^{+}+K^{+}) > (Cl^{-}+SO_4^{2-}) > (CO_3^{2-} + HCO_3^{-})$
7	Alkali metals exceed alkaline earths, and strong acidic anions exceed weak acidic anions	$(Na^{+}+K^{+}) > (Ca^{2+}+Mg^{2+}) > (Cl^{-}+SO_4^{2-}) > (CO_3^{2-}+HCO_3^{-})$
8	Alkali metals exceed alkaline earths, and weak acidic anions exceed strong acidic anions	$(Na^{+}+K^{+}) > (Ca^{2+}+Mg^{2+}) > (CO_3^{2-}+HCO_3^{-}) > (Cl^{-}+SO_4^{2-})$

Fig. 6.6 Chadha Diagram

(i) **Calcium (Ca^{2+}):**

- **Dissolution of calcium-bearing minerals:** Groundwater can acquire calcium ions through the dissolution of calcium-rich minerals such as limestone (calcite), gypsum, and dolomite. These minerals contain calcium carbonate ($CaCO_3$) or calcium sulfate ($CaSO_4$), which can dissolve in water, releasing calcium and sulfate ions.
- **Weathering of carbonate rocks:** Carbonate rocks, including limestone and dolomite, contain a significant amount of calcium carbonate.
- **Biological processes:** The decay of organic matter, such as plant and animal remain, can release calcium ions.

(ii) **Magnesium (Mg^{2+}):**

- **Dissolution of magnesium-containing minerals:** Minerals like dolomite (calcium magnesium carbonate) and magnesite (magnesium carbonate) contain magnesium.
- **Weathering of ultramafic rocks:** Ultramafic rocks, such as serpentinite, are rich in magnesium minerals. Through weathering and erosion processes, these rocks release magnesium.
- **Biological processes:** Biological activities and decay can contribute to the release of magnesium ions into groundwater.

(iii) **Sodium (Na^{+}):**

- **Dissolution of sodium chloride deposits:** Sodium chloride, commonly known as halite or rock salt, can occur as deposits in certain areas.
- **Weathering of sodium-bearing minerals:** Minerals like feldspar and amphibole contain sodium. Weathering and erosion of these minerals can release sodium ions.
- **Saltwater intrusion:** In coastal regions, the intrusion of saltwater from the ocean into freshwater aquifers can introduce sodium ions. This occurs when excessive groundwater extraction or changes in hydrological conditions cause seawater to infiltrate the aquifer.

(iv) **Potassium (K^+):**

- **Weathering of potassium-rich minerals:** Potassium is present in minerals like feldspar and mica that release potassium ions into the groundwater.
- **Leaching from agricultural practices:** The application of potassium-rich fertilizers in agriculture can lead to leaching of potassium into the groundwater, especially in areas with intensive agricultural activity.
- **Biological processes:** Decomposition of organic matter, including plant and animal remains, can release potassium ions into groundwater.

(v) **Bicarbonate (HCO_3^-):**

- **Carbonate mineral dissolution:** Carbonate minerals, such as calcite and dolomite, contain bicarbonate ions. When these minerals dissolve in groundwater, they release bicarbonate ions, contributing to the alkalinity of the water.
- **Atmospheric carbon dioxide absorption:** Carbon dioxide from the atmosphere can dissolve in groundwater, forming carbonic acid. This acid reacts with carbonate minerals, converting them into bicarbonate ions.
- **Decomposition of organic matter:** The breakdown of organic matter in the soil and aquifer can release carbon dioxide, leading to the formation of bicarbonate ions.

(vi) **Sulfate (SO_4^{2-}):**

- **Oxidation of sulfide minerals:**Sulfide minerals like pyrite (iron sulfide) can oxidize when exposed to oxygen and water, producing sulfate ions in the process.
- **Dissolution of sulfate minerals:** Minerals such as gypsum (calcium sulfate) and anhydrite contain sulfate ions. When groundwater comes into contact with these minerals, it can dissolve the sulfate ions.
- **Industrial activities and pollution:** Industrial processes, mining activities, and smelting operations can release sulfate.

(vii) **Chloride (Cl^-):**

- **Saltwater Intrusion:** In coastal areas, chloride ions can enter groundwater through the intrusion of saltwater. Excessive groundwater pumping or changes in hydrological conditions can cause seawater to infiltrate freshwater aquifers, increasing chloride levels.
- **Road Salt and Deicing Agents:** The use of road salt and deicing agents during winter can lead to chloride runoff and infiltration into groundwater. This is particularly common in high altitude urban areas where road salting is practiced.
- **Industrial Discharges:** Certain industrial processes and activities can release chloride-containing chemicals and wastewater into the environment, which may eventually reach groundwater.

(viii) **Nitrate (NO_3^-):**

- **Soil and Water:** Nitrates occur naturally in soil and water due to the decomposition of organic matter, including plants, animals, and other biological materials. Nitrate levels in soil and water can vary depending on factors such as agricultural practices, pollution, and natural processes.
- **Fertilizers:** Nitrate-based fertilizers, such as ammonium nitrate and potassium nitrate, are widely used in agriculture to provide essential nutrients for plant growth. These fertilizers are applied to crops to supplement nitrogen levels in the soil, which can enhance plant growth and increase yields.
- **Food:** Nitrates can be present in various foods, particularly vegetables and cured or processed meats. Vegetables such as spinach, lettuce, beetroot, and radishes naturally contain nitrates. Cured or processed meats, such as bacon, sausages, and ham, can contain higher levels of nitrates due to the use of nitrate-based preservatives during processing.
- **Industrial Sources:** Nitrates can be present in industrial waste, such as effluents from chemical manufacturing or wastewater treatment plants. Industrial processes that involve the use of nitrogen-containing compounds can contribute to the presence of nitrates in the environment. Excessive concentration of Nitrate in drinking water is considered hazardous for infants because in their intestinal tract nitrates are reduced to nitrites, which may cause blue baby syndrome. Hence, nitrate level needs to be maintained in a water body. Nitrate is assimilated by algae and larger hydrophytes. It is reduced to ammonia when molybdenum is provided in the enzyme system associated with the reduction.

6.10 Remedial measures for increasing water quality standard of spring water

The selection of the appropriate remedial measure depends on the specific characteristics of the spring water, including the concentration of the ions, the overall water quality, and the intended use of the water. Here are some common remedial measures for managing and treating groundwater with elevated concentrations of certain ions:

(i) **Calcium (Ca^{2+}) and Magnesium (Mg^{2+}):**

- **Water softening:** Ion exchange systems or water softeners can be used to reduce the hardness caused by calcium and magnesium ions. These systems exchange the calcium and magnesium ions with sodium ions, reducing the hardness of the water.
- **Reverse Osmosis (RO):** RO systems can effectively remove calcium and magnesium ions, as well as other dissolved solids, from water through a semipermeable membrane.

(ii) **Sodium (Na^{+}):**

- **Reverse Osmosis (RO):** RO systems can effectively remove sodium ions from groundwater, improving its quality for drinking and irrigation purposes.
- **Electrodialysis:** Electrodialysis involves the use of an electric field to selectively remove ions from water. It can be used to reduce the sodium content in water.

(iii) **Potassium (K^{+}):**

- **Ion exchange:** Similar to water softening, ion exchange systems can be used to remove potassium ions from groundwater by exchanging them with other ions, such as sodium ions.

(iv) **Bicarbonate (HCO_3^-):**

- **Chemical addition:**Adding lime (calcium hydroxide) or soda ash (sodium carbonate) to the water can help precipitate and remove bicarbonate ions through a process called chemical precipitation.
- **Aeration and Degassing:** By exposing the water to air or stripping it of dissolved gases, bicarbonate ions can be converted into carbonate ions, which are less soluble and can be removed through filtration or sedimentation.

(v) **Sulfate (SO_4^{2-}):**

- **Ion Exchange:** Ion exchange systems can effectively remove sulfate ions from water by exchanging them with other ions.
- **Desalination Techniques:** Desalination methods like reverse osmosis and electrodialysis can be used to reduce sulfate concentrations in groundwater.

(vi) **Chloride (Cl^-):**

- **Dilution:** In some cases, blending the chloride-contaminated groundwater with a clean water source may be a practical solution. This can help reduce the overall chloride concentration to meet regulatory limits or desired levels.
- **Enhanced Recharge and Artificial Groundwater Recharge:** Replenishing the aquifer with fresh water through managed recharge techniques can help dilute the chloride concentration in groundwater over time.
- **Source Control and Best Management Practices:** Implementing measures to control the sources of chloride contamination is crucial. This may include minimizing the use of road salt, implementing stormwater management practices to reduce runoff, and ensuring proper industrial wastewater treatment and disposal.
- **Reverse Osmosis (RO):** RO systems are effective in removing chloride ions from water. They use a semipermeable membrane to separate dissolved salts and impurities from the water, producing treated water with reduced chloride concentrations.

- **Ion Exchange:** Ion exchange systems can be employed to remove chloride ions from water by exchanging them with other ions, such as sulfate or bicarbonate. The choice of the appropriate ion exchange resin depends on the specific water quality characteristics.

(vii) **Nitrate** (NO_3^-):

- **Water Treatment Systems:** Install a water treatment system that is specifically designed to remove nitrates from drinking water. Reverse osmosis, ion exchange, and distillation are common methods used for nitrate removal. These systems can effectively reduce nitrate levels and provide safer drinking water.
- **Testing and Monitoring:** Regularly test your drinking water for nitrate levels. This will help you stay informed about the quality of your water and take appropriate measures if nitrate levels exceed the recommended limits.
- **Source Control:** If high nitrate levels are due to agricultural practices or pollution, it is important to address the source of contamination. Implementing proper agricultural management practices, such as controlled fertilizer application, cover cropping, and buffer zones, can help minimize nitrate runoff into water sources.
- **Dietary Considerations:** If you are concerned about nitrate intake from food, there are some dietary measures you can take. Avoiding or limiting the consumption of cured or processed meats that contain high levels of nitrates can help reduce exposure. Additionally, cooking vegetables can decrease nitrate levels, so consider steaming or boiling vegetables instead of eating them raw.
- **Education and Awareness:** Stay informed about the sources and health effects of nitrates. Educate yourself and others about the risks associated with high nitrate levels and promote practices that help reduce nitrate contamination in water and food sources.

6.11 Data compilation and sharing

To ensure accurate and accessible information, compiling and sharing spring water quality data is very crucial. The Spring Water Quality Analysis Report need to be prepared on regular basis. Following is some of the steps to be undertaken for compilation and sharing of data.

6.11.1 Data compilation

Data compilation is necessary to ensure consistency in units, formatting, and data structures across different datasets. It may involve converting measurements to a standard unit system and standardizing data formats (e.g., CSV, Excel).

6.11.2 Data sharing

If the concentration above the permissible limit is confirmed in repeat sampling, the data is to be shared with the State Government departments which are dealing with water supply issues like PHED/Ground Water Department/Municipal Organizations etc. and Health Department of the State Government. At Central Level, the data is to be shared with Department of Drinking Water and Sanitation, ICMR etc. Once contamination of spring water for any parameter is detected in any of the sampling location, the following approach is to be adopted.

(a) **In the form of a report:**
The spring water quality chapter should be inserted in Ground Water report (in case of study conducted by CGWB) should contain summarized findings, key observations, and conclusions in a comprehensive manner. That should include details about the data sources, methodology, limitations, and any recommendations for further actions. For other department, regular reporting need to be initiated and all India spring water quality report is to be published once four years.

(b) **Online publication :**
This step involves the uploading of spring water quality data by creating a dedicated website or web portal with the public. The data should be accessible, well-organized, and user-friendly.

(c) **Sharing with stakeholders:**
This step involves sharing the compiled data with relevant stakeholders, such as local government agencies, water management organizations, researchers, and environmental NGOs.

Chapter 7

Application of Environmental Isotopes in Hydrology of Springs

7.1 Background

Isotopic data, particularly stable isotopes of hydrogen and oxygen, can be used to identify the sources of recharge water that feeds spring systems. Hydrologists can identify seasonal sources of spring water recharge, such as precipitation, surface runoff, river, lake, snow or glacier, and inflows from deep aquifers, by using isotopic compositions. This provides important information on the primary sources of spring water replenishment. Knowledge of the isotopic composition in spring water and its relation has significant implications in hydrology, including determining the average residence time of water in aquifers, identifying recharge zones, exploring aquifer interconnections, discerning water origins, and analysing process dynamics. The isotopic signatures can help to determine the age of spring water contributing to a better understanding of sustainability and resilience of spring water resources. The stable isotopes along the flow paths can help to identify and quantify the dynamic exchanges in the hydrological cycle, and is crucial for assessing water allocation, addressing water quality issues, and evaluating the potential implications of over exploitation of water use (Kalbus et al., 2006; Sophocleous, 2002). The application of long-term isotopic data derived from springs contributes to the understanding of the impacts of climatic variability, including precipitation patterns and temperature fluctuations, on the spring hydrology. The incorporation of isotopic data into modeling frameworks enables the calibration and validation of predictive models, hence improving the precision and dependability of simulated hydrological processes and flow dynamics.

The isotopic investigations of springs most frequently include the following topics:

- Identification of the aquifer recharge-discharge relationship.
- Assessment of possible source of waters that contribute to the spring discharge.
- Determination of flow paths from the recharge to the discharge area of the spring.
- Groundwater residence time and connected storage properties of aquifer.
- Mixing of event waters (e.g., snowmelt, storms) and present groundwater in the spring discharge.
- Identification of atmospheric sources that contribute to the solute isotopic composition of groundwater.
- Assessment of influences of biologic cycling on the groundwater's solute isotopic composition (e.g., nutrients within an ecosystem).
- Determination of groundwater geochemical evolution.
- Identification of sources and mechanisms of groundwater contamination.
- Testing hydrologic models using isotopic data.
- Estimation of spring water recharge rates.
- Monitoring of long-term hydrological trends and vulnerability to climate change.

7.2 Scopes and limitations of the application of environmental isotopes

Scope:

- Environmental isotopes indirectly provide information on groundwater residence times and mixing processes in the spring catchment which are immensely useful in identification of recharge source and area. These data cannot be obtained by direct measurement.

- Long-term isotopic data reflect changes in the spring recharge-discharge relationship and complement the spring hydrograph data.

- Results of isotopic investigations significantly complement results of classical geological and hydrogeological methods and those of other indirect methods, such as artificial tracers, geophysical investigations, and numerical modelling.

Limitation:

- In situ analyses are not possible. Besides, the isotopic monitoring often requires long-term or frequent sampling for adequate insight into the spring hydrodynamic and geochemical characteristics.
- Automatic samplers offer valuable aid to this work.
- Isotopic investigations are quite expensive, particularly laboratory costs.
- The research methodology should be carefully designed to get significant results, especially in the selection of sampling places and leading parameters as well as the sampling techniques and methods.
- The processing and modeling of isotopic data consider a lot of assumptions, which are sometimes difficult to implement. The data interpretation should consider the uncertainties.

7.3 Stable isotope compositions and calculation method

Stable isotope compositions are generally reported asδvalues in parts per thousand, permil (‰). Theδvalues are given by:

$$(\delta^2 H)‰ \quad or \quad (\delta^{18}O)‰ = \left(\frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}}\right) \times 1000 \tag{7.1}$$

Where, R represents the ratio of heavier to lighter isotope ($^2H/^1H$ or $^{18}O/^{16}O$). R_{sample} and $R_{standard}$ are the isotope ratios in the sample and the standard, respectively. $\delta^2 H$ and $\delta^{18}O$ values are reported relative to Vienna Standard Mean Ocean Water (VSMOW). The sample is termed as depleted if theδvalues are lower, and as enriched if the δ values are higher with respect to a reference.

7.4 Seasonal variability of isotopic signatures in rainfall and springs

The seasonal fluctuations of stable isotopes ($\delta^2 H$ and $\delta^{18}O$) in rainfall and springs are crucial for understanding water transport dynamics in hydrological systems. The isotopic signatures of rainfall and spring water can fluctuate during a single season due to changes in precipitation patterns, temperature changes, and the influence of local climatic circumstances. These seasonal variations serve as an indication of the complicated relationship between meteoric water sources and the distinctive hydrogeological attributes of the spring catchment area. Furthermore, evaluating inter-seasonal fluctuations over longer time periods can reveal long-term trends and patterns driving spring recharge and outflow dynamics. Hydrologists are able to determine the seasonal variations in groundwater replenishment, the impact of climate variability on aquifer storage, and the responsiveness of spring systems to changing environmental conditions by monitoring the isotopic compositions of rainfall and spring water across numerous seasons.

Understanding intra- and inter-seasonal variations in spring and rainfall is critical for designing effective water resource management plans and conservation measures, especially in areas where water availability is subjected to seasonal fluctuations. The integrating isotopic data with comprehensive hydrological monitoring data can help to understand the seasonal dynamics of spring hydrology that can help to make informed decisions regarding the sustainable utilization and protection of spring water resources.

7.5 Sampling protocol

To ensure accurate and reliable results during the collection of stable isotopes, it is important to follow a standard operating procedure (SOP). Here is a suggested SOP for sample collection for stable isotopes:

- Thoroughly clean and sterilize sampling equipment before use.
- Identify sampling sites based on research goals and environmental factors.
- Consider factors such as geographical diversity, ecosystem type, and accessibility to determine representative sampling locations.
- Collect water samples using clean, acid-washed polyethylene bottles, ensuring that the bottles are filled to capacity without introducing air bubbles (Fig. 7.1a and Fig. 7.1b).
- Minimize sample exposure to external contaminants by wearing appropriate personal protective equipment, such as gloves and masks, during the collection process.

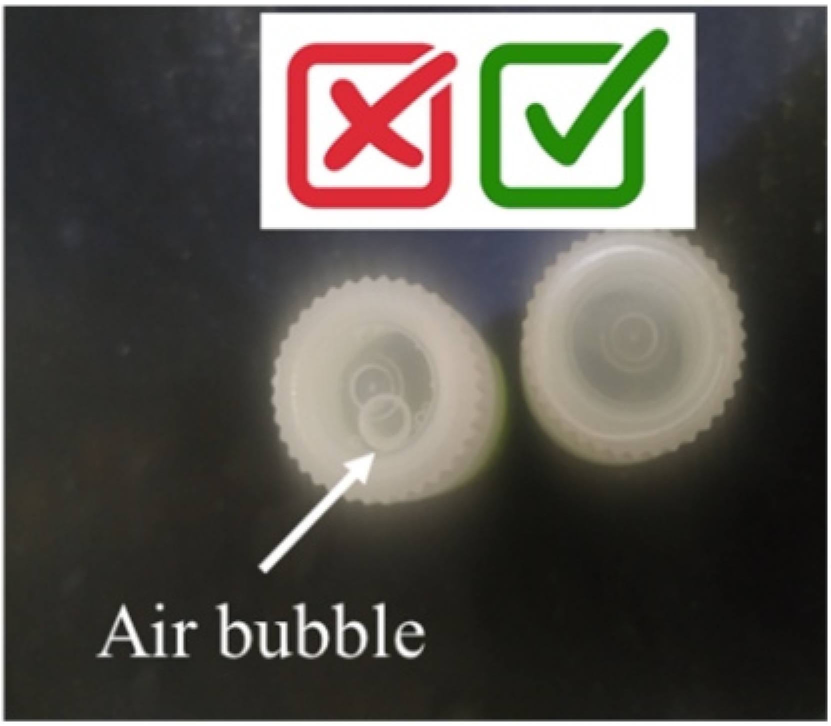
- Record location, date, and environmental conditions for each sample.
- Maintain a detailed log of the collection process, noting any deviations.
- Store the collected samples in appropriate containers, ensuring that the containers are labelled with the necessary information and securely sealed to prevent any sample leakage or contamination.
- Preserve samples at suitable temperatures and lighting conditions.
- Securely pack the samples for transportation, taking necessary precautions to prevent any physical damage during transit.
- Conduct regular checks to ensure that the samples remain uncontaminated and representative of the specific environment under study.

7.6 Delineation of spring recharge elevations

The stable oxygen and hydrogen isotopes play an important role in identifying the recharge altitudes and zones of springs within a catchment. The identification of dominant recharge elevations that contribute to spring flow can be achieved through the comparison of the isotopic signature of spring sources with the altitudinal gradient for $\delta^{18}O$ and $\delta^{2}H$ in rainfall and comparing it to Local Meteoric Water Line (LMWL). The isotopic composition of rainfall exhibits altitude-dependent variations as a result of temperature-dependent fractionation mechanisms occurring during the processes of condensation and precipitation. The isotopic composition of rain samples collected at different altitudes (Fig. 7.2) along the hillslope exhibits different isotopic signatures, which contribute to the development of a LMWL (solid line in Fig. 7.3).

Isotopic signature of spring water falls on LMWL which clearly indicates that the source of spring water is meteoric water. Any deviation of spring isotopic signature from LMWL may imply the occurrence of fractionation in rainfall before joining the recharge area. Such investigations may be useful for understanding the recharge of spring by other possible sources or combination of sources. The determination of the altitude of the recharge areas of aquifers that supply water to the springs can be achieved by establishing an altitudinal gradient through the measurement of stable isotopic compositions of rainfall at various altitudes within a catchment (Fig. 7.4). The approach is comparing the isotopic compositions of rainfall samples taken at different elevations along the hillslope with those of spring water (Fig. 7.2). This

(a) Sampling of Spring water for Stable isotopic analysis



(b) Polyethylene bottles (15 ml) used for sample collection, demonstrating the importance of filling to capacity without entrapping air bubbles

Fig. 7.1 Spring water collection for isotope analysis

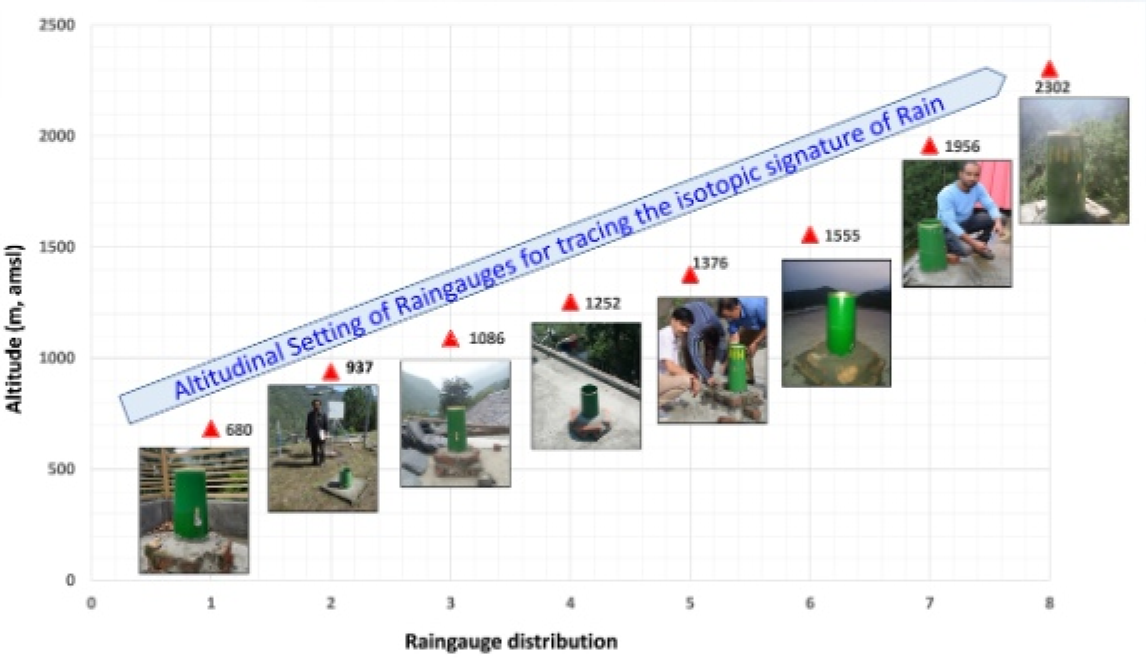


Fig. 7.2A typical example of altitude-wise (680-2302 m, amsl) field set-up of Ordinary Raingauges (ORGs) in a catchment to capture the altitudinal signature of rain

comparison makes it feasible to establish the altitude range where the isotopic signatures of spring water coincide with the signatures of the appropriate recharge areas in the catchment. The relationship between isotopic compositions and altitude is a useful tool for identifying the elevation ranges that contribute to spring water replenishment and establishing the spatial distribution of spring recharge zones.

Figure 7.4 presents an example showcasing the method used to estimate the mean catchment elevation of five distinct springs. In this specific case, the first spring (SP1) is determined to have a mean catchment elevation of 1200 *m amsl*, while the second spring (SP2) has an elevation of 1950 *m amsl*. Similarly, the third spring (SP3) has a mean catchment elevation of 2350 *m amsl*, the fourth (SP4) and fifth spring (SP5) has a 2750 *m amsl*, and 3150 *m amsl* mean catchment elevation, respectively. This example highlights the variation in catchment elevations and emphasizes the relevance of understanding these elevations in the context of the recharge processes.

It is of the utmost importance to ascertain whether the recharge region is a singular recharge area, a composition of many recharge areas located at different elevations, or if it comprises of a variety of recharge sources or a combination of these. Isotopic data provide an average recharge altitude, which may reflect a mixing of

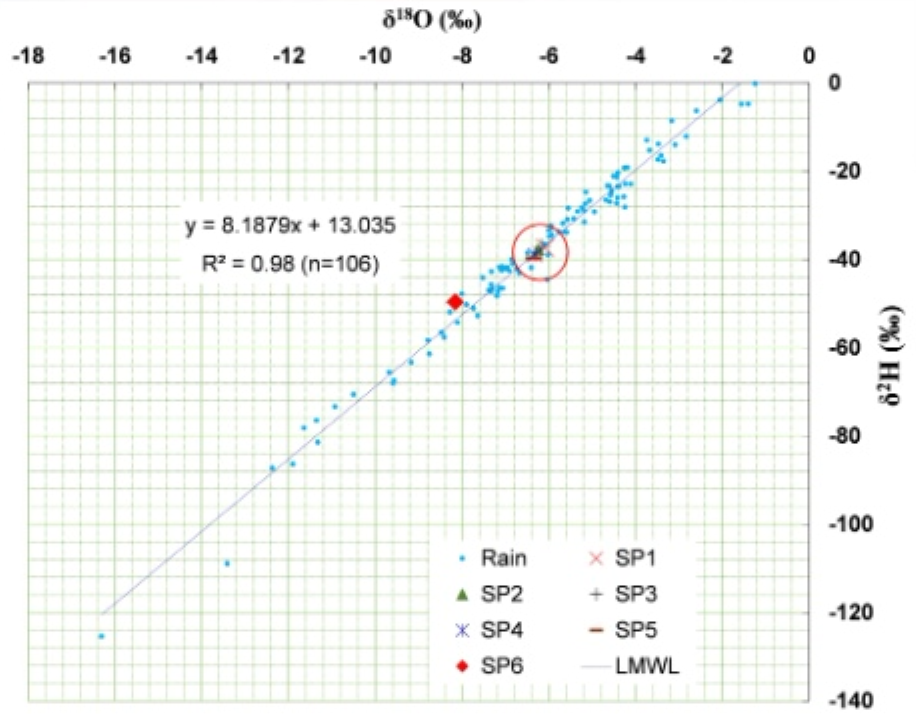


Fig. 7.3 Plot of isotopic values of different springs along with developed LMWL for the study area (SP denoted for Spring)

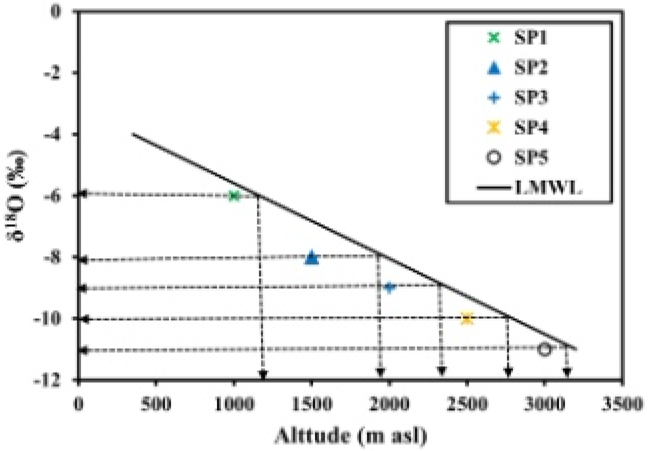


Fig. 7.4 $\delta^{18}O$ and $\delta^{2}H$ values of rainfall *vs* altitude showing the recharge elevations of springs

tion. Therefore, to get accurate interpretations, it is imperative to engage in close collaboration with hydrogeologists, since their expertise allows for the elucidation of multiple potential scenarios based on geological and hydrological data.

7.7 Age determination of spring water

The assessment of the age of spring water is a fundamental component in understanding the intricacies of groundwater movement and recharging mechanisms. Environmental isotopes and tracers are among the techniques utilized to determine the age and average residence time of spring water. Tritium (^{3}H) is employed in age estimation owing to its radioactive properties and its ability to serve as a distinctive time signature for groundwater. Based on historical tritium levels, spring water ^{3}H can be linked to atmospheric nuclear testing in the 1950s and 1960s to estimate water age. In addition, the age of relatively older spring water can be determined using radiocarbon dating (^{14}C) techniques, which can shed light on the recharge rates and renewal timescales of groundwater. The carbon dynamics and age distribution of organic matter in spring water can be better understood with the use of ^{14}C dating when combined with other isotopic measurements. It is crucial to understand the age of spring water in order to assess the sustainability and resilience of water resources, particularly in areas where springs are essential supplies of freshwater for ecosystems as well as for human communities. The establishment of effective strategies for the management and protection of spring water resources can be achieved by integrating age determination methods with thorough hydrological monitoring. In view of some unique capabilities of isotopic techniques, it makes excellent supplement technique in hydrogeological investigation, however its use in isolation is not recommended.

Chapter 8

Treatment Measures for Springshed Management

8.1 Background

To revive natural springs, adequate treatment measures through a combination of biological/agronomical practices and engineering interventions are required to be implemented in springsheds. These interventions aid in augmenting recharge, enhancing storage, and checking soil erosion within the springsheds. Consequently, these measures contribute to the rejuvenation of springs and maintaining the sustainability of the springs (quantity and quality) in the mountainous regions. Furthermore, an integrated approach is necessary for managing streams and lakes within the springshed/watersheds. Therefore, it is imperative to identify and develop standard protocols/ guidelines for various treatment management measures for SSM. Standard Operating Procedures (SOP) for SSM, encompassing various treatment measures, are provided to practitioners to equip them with a comprehensive understanding of SSM practices in mountainous regions.

8.2 Vegetative measures

Vegetative measures protect water bodies and watercourses by trapping sediments and pollutants originating from up-slope land uses and activities. Simultaneously, these measures can influence the rate of runoff by enhancing soil infiltration and the soil water-storage capacity. Therefore, it becomes crucial to implement suitable site-specific measures, which could either be vegetative, engineering, or a combination of both, to prevent the degradation of the springshed caused by various natural and anthropogenic activities.

In general, vegetative measures are implemented on non-mild sloppy land to control erosion and conserve water. Application of vegetative measures which also play the second line of defence after engineering measures, is entirely dependent upon the soil types, land slope and rainfall characteristics. These measures are not only cost-effective but also exhibit long-lasting and substantial effectiveness. However, considering the multifaceted role of vegetation in geo-morphological protection, stabilization of the soil and ecological development in degraded areas of springshed/watersheds, it is necessary to re-vegetate the area with appropriate native species and proactive interventions as required.

The success of vegetative measures depends on the careful selection of species and the use of proper planting and establishment techniques. In order to enhance the soil moisture level of barren/degraded slopes, various measures such as mulching, application of geotextiles (Fig. 8.1) and the spreading of topsoil on degraded land, need to be adopted.

Fig. 8.1 View of geotextile used for topsoil stabilization and soil moisture conservation

The detailed vegetative measures for soil and water conservations (Fig. 8.2

and Fig. 8.3) are given below:

(a) Contour cultivation

(b) Strip Cropping

- Contour strip cropping
- Field strip cropping
- Buffer strip cropping
- Wind strip cropping

(c) Tillage practices

- Mulch Tillage
- Vertical mulching
- Minimum tillage
- Conventional tillage
- Listening

(d) Soil management practices

(e) Supporting Practices (Inter planting, fertilizer application)

(f) Vetiver grass planting

Fig. 8.2 Contour cultivation

Fig. 8.3 Mulch tillage

8.3 Soil moisture conservation and slope stabilization through native grasses

Grasses and herbaceous species available locally in abundance can be effectively utilized for biological treatment. Seedlings can be collected from surrounding and nearby areas without causing damage to the existing grass cover. These species often exhibit superior tolerance to drought, rapid growth in low-nutrient soils, and resilience to various climatic stresses. Additionally, their fibrous roots play a significant role in mitigating soil erosion and ultimately contribute to the development of an organic soil layer, facilitating the colonization of early succession species (Institute, 2018). The following principles are applicable in the biological treatment of degraded areas/springshed:

- Native species of trees, shrubs and herbs should be planted. A combination of variables must be used rather than opting for pure plantation.
- Pits for planting should be dug sufficiently in advance, following standard practices in the plantation area. However, the period between pit digging and scheduled planting time should not exceed four months to minimize soil accumulation caused by wind and water erosion. The pits should be refilled after digging.
- Organic manures should be applied to boost plant growth in the plantations. Eco-friendly measures viz., physical or mechanical methods and use of natural products should be employed for weed and pest control, avoiding the use of synthetic chemicals.
- Adequate protection against all types of biotic and abiotic disturbances should be effectively provided to planted seedlings for five years through fencing, vigilant monitoring, and raising public awareness.
- Native species recommended for the suggested model must be used for plantation. The propagation method and special attributes of various species are indicated in Table 8.1.

Furthermore, specific species suitable for the plantation in the mountain regions [Himalayan Landscape (Himachal Pradesh, Jammu Kashmir, Uttarakhand, Sikkim, Arunachal Pradesh, Meghalaya, Manipur, Assam (Hill districts), Mizoram, Nagaland, Tripura (Hill districts), West Bengal (Darjeeling) of India are provided in Table 8.2.

Table 8.1: Suitable native plant species for 1800 m to 2200 m amsl

Provide name	Shrub or small tree species	Herbaceous flora
Alnusnepalensis	Rhusparviflora	**Bryophyte species for erosion control:**
Grewiaoptiva	Coriarianepalensis	Barbulaconstricta,
Sapiumbaccatum	Ficusroxburghii	Bryumcellulare
Symplosos	Asparagus adscendens	Bryumcapillare
Bauhinia purpurea	Berberisasiatica	Didymodonrecurvus
Melia azedarach	Viburnum continifolium	Plagiochasmaappendiculatum
Albizziachinensis	Viburnum mullaha	Targioniahypophylla
Albizzaprocera	Ficuspalmata	Asterellawallichiana
Aesculusindica	Prinsepiautilis	
Boehmeriarugulosa	Rubusellipticus	**Pteridophyte species for erosion control:**
Quercusleucotrichophora	Debregeasialongifolia	Selaginella chrysocaulos
Celtisaustralis	Phoenix humilis	Polypodiodes microrhizoma
Terminalia chebula	Hypericumoblongifolium	Cheilanthes albomarginata
Cornusoblonga	Cotoneaster roseaus	
Kydiacalycina		**Angiospermic species:**
Ficuscunia	**Fast growing bamboo grass species**	Urtica parviflora
Populus ciliate	Thysanolaena maxima	Rumex nepalense
Lyoniaovalifolia	Drepanostachyumfalcatum	Origanum vulgare
Daphanepapyrace	Sinarundinaria anceps	Carex cruciata
	Imperatacylindrica	Anaphalis spp.
	Cymbopogondistans	Commelinabenghalensis
		Inulacappa
	Fast growing climber species	Sonchus asper
	Ichnocarpusfrutescens	Impatiens spp,
	Hederanepalensis	

Table 8.2: Details species for plantation in the mountain regions of India

S.No.	Plant Habit	Species
1	Tree	**For Sub-Himalayan to Himalayan Temperate Area:** Abies, Pinus wallichiana, Alnus nepalensis Rhododendron arboreum, Rhododendron dalhousieae, Rhododendron griffithianum, Juniperus spp., Aglaia spectabilis, Canarium resiniferum, Elaeocarpus sphaericus, Horsfieldia kingie, Livistona jenkinsiana, Polyalthia simiarum, Tetrameles nudiflora, Vatica lanceifolia, Pterygota alata, beilschmiedia roxburghiana, Phoebe spp., Pyrus spp., Dysoxylum spp., Quercus spp., Ougeinia oojeinensi, Diploknema butyracea **For Alpine Areas:** Rhododendron barbatum, Rhododendron campanulatum, Juniperus spp.
2	Shrub	**For Alpine Areas:** Berbaris spp, Rhododendron anthopogon, Rhododendron lepidotum, **For Himalayan Temperate Area:** Berbaris spp, Rhamnus spp., Caragana brevispina, Indigofera spp., Lespedeza spp., Desmodium spp. Prinsepia utilis, Pyracantha crenulata, Cotoneaster spp., Woodfordia
3	Herb	Desmodium spp.,
4	Grasses	**For Terai Region of Himalaya:** Narenga porphyrocoma, Saccharum bengalense, Saccharum spontaneum, Erianthus ravennae, Phragmites australis, Arundo donax, Cymbopogon flexuosus, Vetiveria zizanoides, Arundinella bengalense, Bothriochloa bladhii, Sorghum nitidum, Chionachne koenigii, and Coix lachryma-jobi. **For sub-Himalayan tropical hill savannas and Shiwaliks:** Chrysopogon fulvus, Neyraudia arundinacea, Arundinella bengalensis, Aristida cyanantha, Heteropogon contortus, and Imperata cylindrica whereas the Aravallis have more of Cenchrus spp., Aristida adscencionis, Panicum, Chloris virgata, Eremopogon and Dichanthium annulatum.

Table 8.2 continued from previous page

S.No.	Plant Habit	Species
		For Himalayan Sub-Tropical Area: Chrysopogon fulvus, Arundinella nepalensis, Pennisetum orientale, Apluda mutica, Heteropogon contortus, Cymbopogon distans, Imperata cylindrica, Capillipedium parviflorum, Microstegium ciliatum
		For Himalayan Temperate Area: Chrysopogon gryllus, Andropogon tristis, Themeda anathera, Themeda tremula, Erianthus rufipilus, Miscanthus nepalensis, Brachypodium sylvaticum, Bromus unioloides
		For Alpine Areas: Danthonia cachemyriana, Festuca, Bromus, Briza, Calamagrostis, Agrostis
		Northeast Hills (Mainly for Manipur, Nagaland, Mizoram and hills of Assam: Festuca, Bromus, Arundinella, Agrostis, Cyathopus, Coix, Tripsacum, Cymbopogon, Themeda villosa, Microstegium, Glyceria, and Gymnopogon
		Microstegium, Erianthus, Narenga fallax, Thysanolaena maxima)

8.3.1 Species selection

Following points should be taken into consideration while selecting the plant species:

- Adaptation to the existing climate and soil condition of the area,
- Preference for native colonizing species with strong root-shoot systems, soil binding characteristics and ample foliage cover,
- Consideration for nitrogen-fixing plants, which can ameliorate the soil by the addition of organic matter through plant litter/root decay,
- Selection of species that can attract and support diverse wildlife, including birds, butterflies, and other forms of fauna. Such species should also have social and economic value to the local population.

8.3.2 Methods of propagation

(i) **Seed sowing:** Seed sowing should ideally take place just before the onset of southwest monsoon, preferably in the months of May and June. Numerous species can be propagated directly through seed sowing/broadcasting. The seeds of the selected species can be collected either from adjoining forested areas or purchased from local markets. Prior to broadcasting, the seeds should be cleaned to remove impurities. The selected species should ideally serve multiple purposes, including timber production, fodder, medicinal properties, edibility, soil binding, and soil enrichment, etc.

(ii) **Broadcasting seeding:** It involves placing the seeds on the soil surface, typically done manually by hand. In certain situations, a combination of seed broadcasting and drill seeding can be employed.

(iii) **Seed mixed soil ball:** Species with small seeds that are well-suited to the local climatic conditions can be sown by preparing seed mix soil balls or seed mix slurry (Fig. 8.4 and Fig. 8.5). Several grass species are effectively sown by seed mix soil balls and slurry. For the composition of seed mix soil balls with a diameter of 8-10 cm, a typical recommendation is to use 60% soil combined with 40% locally available organic manure. These seed mix soil balls can be prepared and then broadcasted across the area for restoration of the degraded mine overburden. Similarly, for the preparation of seed mix slurry, the seeds are first mixed with soil and manure, and then slurry is prepared by adding an appropriate quantity of water. The seed mix slurry is then spread over the area either manually or by applying hydraulic pressure.

(iv) **Hydroseeding:** It is the process of applying a mixture of seeds, fertilizer, fiber mulch, and water to the soil using a hydraulic applicator. Hydraulic seeding is successfully practiced to stabilize barren steep slopes of overburden dumps and fragile unstable surfaces. The system requires large volumes of water, seeds, fertilizer and mulch, which are applied on the surface in the form of a fine spray.

Fig. 8.4 Mixing of seeds in soil

Fig. 8.5 Seed-mixed soil balls

8.3.3 Planting

Planting can be done by various means:

(i) **Seedling:** Species that are planted through seedlings are primarily raised in nurseries before being transplanted at the specific site. At the time of planting, the polybags raised seedlings require careful removal from the polybags and planting into the previously dugout pits of size $2 \times 2 \times 2$ ft. The dugout pits are to be filled with a mixture of pit excavated material, topsoil, and farmyard manure in a ratio of 2:1:1.

(ii) **Rootstock:** Rootstock as in the case of grasses can be planted.

(iii) **Rhizome:** Rhizome as in the case of bamboo can be planted.

(iv) **Stem cutting:** Many species like *Vitexnegundo* can be propagated by stem cutting.

(v) **Slip/culms/clumps/rootstock:** The species such as grasses can be planted through slips, culms, clumps, rootstock etc.

8.3.4 Plantation along the contours

Contour bunds are one of the economical techniques in watershed/SSM. The contour bunds are constructed across the slope instead of up and down the slope with a plain level, where the slope varies from 0 to 5% to avoid the distribution of water and capture more volume of runoff water. They can be practiced in areas with rainfall ranging from 200 mm to 750 mm (Critchley et al., 2013). The distance between earth bund contours varies from 5 to 10m(Mohamed et al., 2010) (Fig. 8.6).

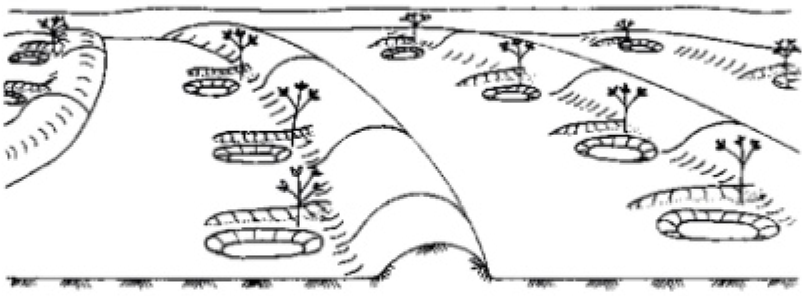


Fig. 8.6 Contour bunds to groundwater recharge

8.3.5 Model estimates for plantation

The total cost of the vegetative measures can be estimated based on planting materials, labour cost and other associated requirements. For demonstration purpose, unit cost estimation for a plantation model is presented in Table 8.3.

Table 8.3: Various heads to be considered for unit cost estimation for plantation model

S. No.	Particulars
A	**Cost analysis for tree plantation:** **(i) Advance soil working:** Pit size ($2ft \times 2ft \times 2ft$), Plant spacing $3m \times 3m$, No. of plants or pits = 1100 per ha **(ii) Transplanting activities:** Manuring, Planting material for 1100 Plants, Planting cost (Assuming 20 plants transplanted by one-man-day, normally 55 man-days/ha)
B	**Cost analysis for shrubs** **(i) Advance soil working:** Pit size ($1ft \times 1ft \times 1ft$), No. of pits 200/ha **(ii) Transplanting activities:** Manuring, Planting material for 200 Plants, Planting cost (say 30 plants transplant by one-man-day, normally 7 man-days/ ha)
C	**Cost analysis for seed sowing of grasses and leguminous** Seed cost (Approx. 5kg/ha), Soil and manure for preparation of seed ball, Soil mix seed ball preparation (Approx. 12 man-days), Broadcasting of seed ball (5 man-days)
D	Contingency [5% of (A+B+C)]
E	Total Cost [A+B+C+D]
F	Maintenance cost 20% of E for first year, 15% of E for second year ,10% of E for third year, 5% of E for fourth year
	Grand Total [A+B+C+D+E+F]

8.4 Engineering measures

Variations in percentage slope play a crucial role in determining the suitable engineering measures in the watershed/springshed. The selection of these engineering measures (Fig: 8.7) can be decided based on many other criteria combined with slope and rainfall criteria. Treatment measures for springshed should be selected based on a comprehensive assessment of factors such as slope, rainfall pattern, soil characteristics, land use, land ownership, hydrogeological conditions, recharge zones of the springs in the springshed and community needs.

Fig. 8.7 Engineering measures for soil and water conservation

Engineering measures criteria applicable for watersheds can be used for SSM based on the guidelines of the Integrated Mission for Sustainable Development (IMSD, 1995) as provided in Table 8.4. For example, percolation ponds are suggested for areas with a slope of less than 10%, and check dams for slopes less than 15%. Groundwater recharge could be applied using check dams and percolation tanks/ponds in the areas characterized by slopes of less than 15% where potential runoff varies from medium to low, respectively. On the other hand, areas with a slope of more than 15% are not recommended for rainwater harvesting due to the lack of regular distribution for runoff and economic costs. The steeper slope creates soil erosion problems, which lead to complications in the design of the storage system.

Table 8.4: IMSD guidelines for rainwater harvesting structures

Structure	**Slope (%)**	**Porosity & Permeability**	**Runoff potential**	**Stream Order**	**Catchment area ($\times 10^4 m^2$)**
Farm ponds	0-5	Low	Medium/ High	1	1-2
Check Dams	<15	Low	Medium/ High	1-4	>25
Gully plug	15-20	Low	High	1	-
Percolation pond	<10	High	Low	01-4	25-40

8.4.1 Major steps for bio-engineering measures

The major steps for bio-engineering measures include:

- Analysing primary and secondary data such as, rainfall, topographic, drainage network, and land use/land cover (LULC).
- Demarcation of micro-catchments/springshed using different approaches such as geological mapping, chemical and isotopic analysis and remote sensing-based methods.
- Identification of suitable locations in the springshed/catchment for implementing appropriate vegetative and engineering measures.
- Soil Conservation Service Curve Number (SCS-CN) and Rational method can be used to estimate peak runoff potential and volume of runoff from the catchment to appropriately design the water harvesting structures.
- Developing detailed design and cost estimates for bio-engineering measures aimed at groundwater recharge, storage and soil conservation in the hilly terrains.
- Ensuring Operation and Maintenance (O&M) of the adapted bio-engineering measures.

The detailed engineering measures are given below and some of the measures are presented in Fig. 8.8.

(i) **Terracing:**

   (a) Diversion terrace
      - Magnum type
      - Nichols type
      - Broad based type
      - Narrow based type

   (b) Retention Terrace

   (c) Bench Terrace

(ii) **Contour Bunding:**

   (a) Narrow based

   (b) Broad based

   (c) Side bunds

   (d) Lateral bund

   (e) Supplemental bunds

   (f) Marginal bund

   (g) Shoulder bund

(iii) **Contour Trenches:**

   (a) Staggered contour trenches

   (b) Continuous contour trenches

8.4.2 Main springshed recharge structures

(i) **Contour Trenches:**

   (a) **Staggered Contour Trenches (SCT)**: These are small rectangular structure constructed on sloping land in a staggered manner (Fig. 8.9). It is important to note that the slope of the walls should not exceed 45°. It has been experienced and observed that recharge structures built on higher slopes steeper than 45° can become unstable and even contribute to landslides. For slopes with a gradient of less than 50% and no existing trail or natural depression, SCTs are considered the most suitable recharge structure for groundwater replenishment. On steeper slopes (ranging from

(a) Diversion terrace

(b) Contour bunding

(c) Water harvesting structures

Fig. 8.8 Engineering measures for springshed management

35° to 50°), it is advisable to dig trenches with lesser depth, as outlined in Table 8.5.

Purpose: Contour trenches are used to break up the slope surface, slowing down the runoff, facilitate infiltration, and trap sediments.

Fig. 8.9 Staggered contour trenches

Table 8.5: Trenches design on sloping land

Slope (%)		<30	30-40	40-50
Size of trench	**Length** (m)	2	2	2
	Width (m)	1	0.6	0.6
	Depth (m)	0.6	0.6	0.45
Volume of trench		1.2	0.72	0.54
Total trenches per ha **(nos.)**		150	180	200
Storage of water m^3 **per ha**		180	130	108

(b) **Continuous Contour Trenches (CCT):**The CCT are essentially suitable in low rainfall areas for moisture conservation (Fig. 8.10). The length of the CCT can be 10-20 m across the slope and the cross-section of the CCT varies 30×30 cm to 45×45 cm.

(ii) **Feeder Channel:** Feeder channels from both sides of the trenches and ponds collect maximum runoff and feed into the pond and trenches.

Fig. 8.10 Continuous contour trenches

Purpose: Act as a sort of diversion to collect the maximum runoff possible and feed into ponds or trenches for further possible infiltration.

(iii) **Terraced fields:** Terraced fields reduce the surface runoff as the steps help in slowing down the speed of water and increase the opportunity time for ground water recharge (Fig. 8.11). These terraces serve as barriers to break slope length and reduce the degree of slope to slow down the runoff and allowing time for groundwater recharge. Average rainfall, soil type, soil depth and average slope of the area should be considered for designing of the terraces for the particular area. Several type of terraces such as level or tabletop terrace, sloped terrace (slope outward), reverse-slope terrace (sloping inward), slope-separated terraces, level benches, level ditches, fish scale pits (half-moon terraces), broad-base terraces, wave-like etc., (Fig. 8.12) can be constructed in view of the average rainfall, soil type, soil depth and the average slope of the area.

(iv) **Percolation/recharge pond:** It is a rectangular dugout structure, constructed usually in a natural depression area on sloping land. Digging pond in natural depressions, will collect maximum runoff which percolate slowly recharge the aquifer which help to maintain the longevity of the flow of the springs in the area. Some typical shapes of the percolation tanks are depicted in Fig. 8.13.

Fig. 8.11 Terraced fields

(v) **Check dams:**

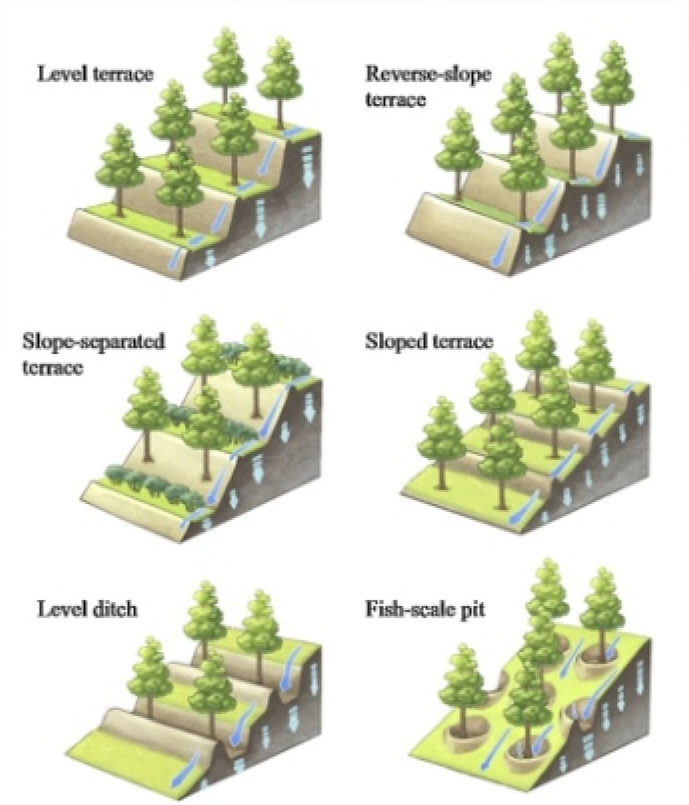
(a) **Brushwood check dam:**

Brushwood check dam is an erosion control and water management structure commonly employed in sloping terrain and in regions prone to soil erosion and sedimentation. To slow down the flow of water on slopes and channels, reducing its erosive energy and facilitating to recharge the downstream area. These dams are constructed using locally available materials, such as wooden poles and brushwood. A typical example of Brushwood check dam made by using locally available pine leaves and demonstrated at Divisional Forest Range, Narendranagar, Tehri Garhwal, Uttarkhand is depicted in Fig 8.14.

(b) **Loose boulder check dam:**

Loose boulder/stone check dams across the small channel/stream or in V-shape valley portion can be constructed for slowing down the flow of water and retain it. At the same time, it increases the chances of infiltration of water in underground system (Fig. 8.15).

Purpose: Usually for 1st or 2nd order streams to decrease the velocity of flowing water along the channel/stream and for water pondage and infiltration.

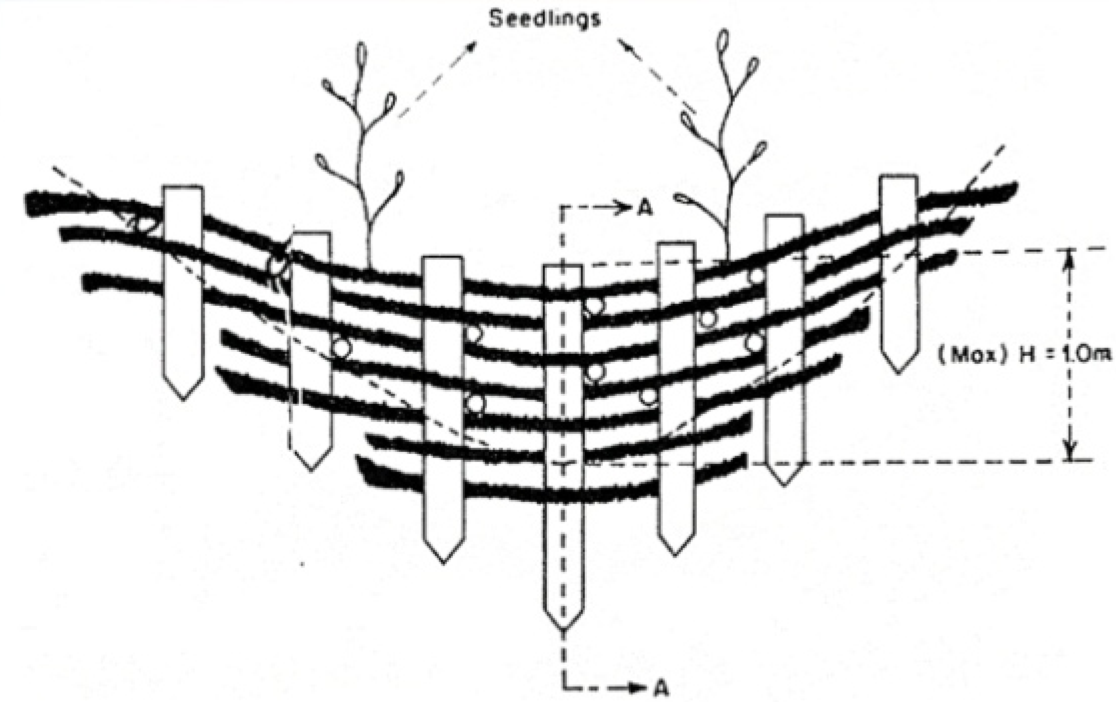


(Source: Chen et al., 2020).

Fig. 8.12 Different terraces that can be constructed in the springshed to enhance the soil moisture

(Source: Divisional Forest Office, Narendranagar, Tehri Garhwal)

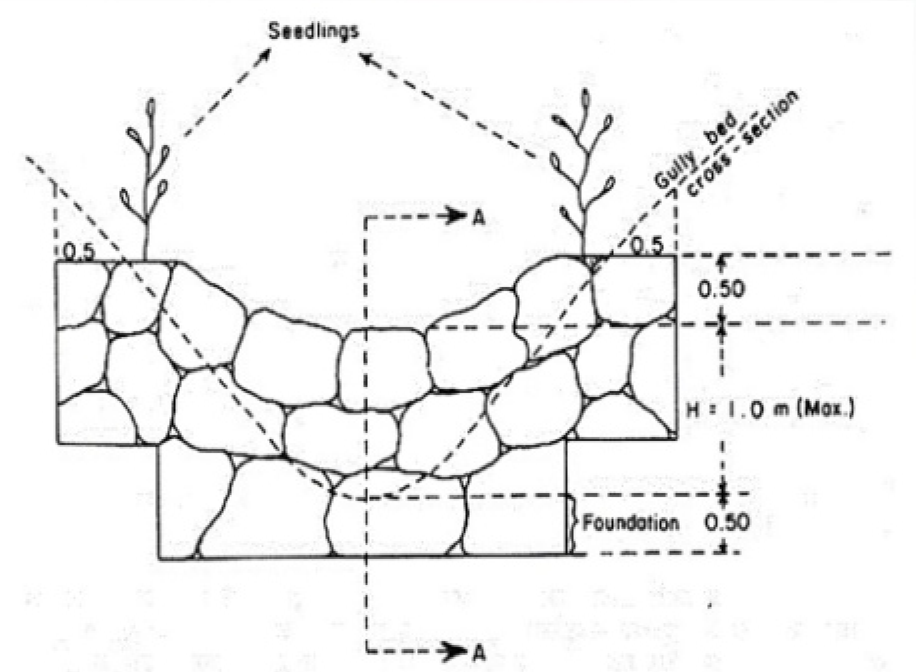
Fig. 8.13 Percolation/storage Pond



(a) Schematic view

(b) Field view

Fig. 8.14 Brushwood checkdam



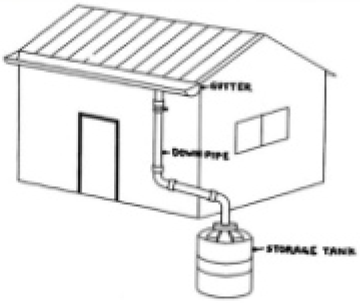
(a) Schematic view

(b) Field view

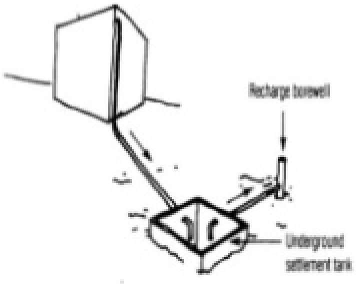
Fig. 8.15 Loose boulder/stone check dams

(vi) **Rooftop rainwater harvesting (RWH):**

Collection of rainwater from roof tops, before it is lost as surface runoff, for domestic needs and groundwater recharge through storage and perforated tank system (Fig. 8.16). The aim of RWH system is to capture, storage and facilitate artificial recharge using freely available rainwater in the springshed area.



(a) Roof Water Harvesting



(b) Recharge Bore Well

Fig. 8.16 Rainwater harvesting

8.4.3 Precautions while selection of sites for engineering measures

Below are some precautions to consider when selecting sites for engineering measures:

- Pay attention to important factors such as slope gradient, soil type, expected water flow or amount of rainfall while designing and implementing engineering measures.
- Avoid areas having history or signs of landslides and/or slope failure.

- Avoid areas where the site or soil is not stable and can't hold the ponded water.
- Refrain from selecting high-slope areas for engineering measures.
- To the maximum possible extent minimize grazing activities in spring recharge area.
- Ensure regular maintenance of constructed engineering measures like desilting to maintain their storage volume.
- large size recharge ponds should be fenced to prevent domestic animals from falling into them.

In summary, various guidelines can be considered for formulating the springshed treatment measures to maintain spring source sustainability. The best options can be selected based on various constraints such as space availability, cost, water requirement, etc. Site specific suitable treatment measures need to be selected in recharge areas of the springshed. This includes the identification of location for storage of water from surface runoff, with appropriate storage areas designed for economic feasibility and structural stability. Constructing suitable storage structures across stream in the catchment/springshed can effectively harvest surface runoff and aid into the groundwater recharge. Furthermore, it is essential to implement appropriate soil conservation measures, particularly in areas with exposed soil, to prevent soil erosion. Approximate locations of the structures can be identified through hydrogeological field survey and investigations to facilitate the design and implementation of treatment measures. Periodic maintenance of the rainwater harvesting structures is vital to increase their life and efficiency.

Chapter 9

Hydrological Analysis of Spring Flow for Sustainable Springshed Management Programme

9.1 Background

Assessment of any SSM programme is an important and critical task, as it requires the data on pre- and post-springshed treatment interventions. Discharge is the most important parameter in the spring hydrology, as it results of various visible and invisible processes that affect the overall water yield of a spring. Therefore, discharge data of a spring holds immense significance in assessing the impact of SSM programme. It is always preferable to collect data at daily scale, however, considering site and manpower limitations, discharge data collection at weekly to bi-weekly interval can be considered. In this chapter various hydrological indices are discussed which can be estimated based on the available spring flow data. Such indices are also very helpful to assess the impact of the SSM programme, which is illustrated through a case study of the Dhara Vikas programme implemented by the RMDD, Sikkim during 2008-12.

9.2 Discharge measurement

Accurate and adequate discharge data are the prerequisite for hydrological analysis of the spring behaviour. Spring flow measurement has already been described in Chapter 3. However, a particular method or instrument is suitable for the measurement of the spring of interest is largely depending upon opening of the spring and field condition. Therefore, field visit is recommended before planning the spring flow measurement.

9.3 Understanding aquifer characteristics through discharge pattern

9.3.1 Spring hydrograph

Spring hydrograph is basically a chronological plot of spring discharge over time. In Fig. 9.1, a conceptual representation of a spring hydrograph is depicted as suggested by Kresic & Bonacci (2010).

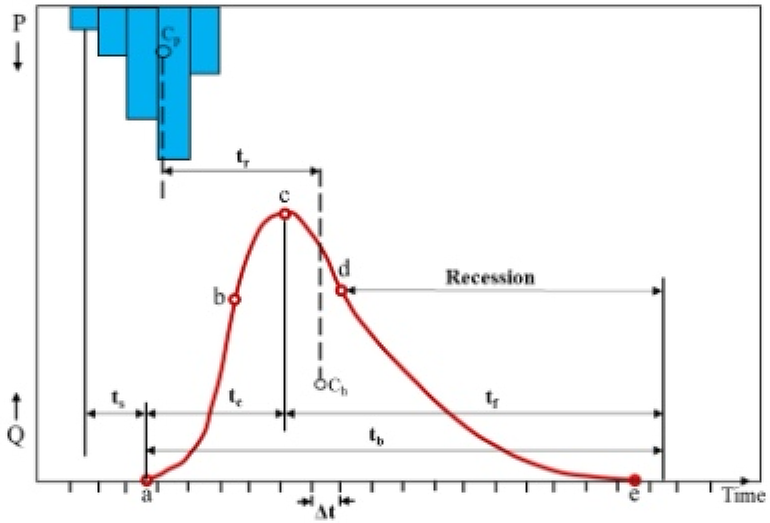
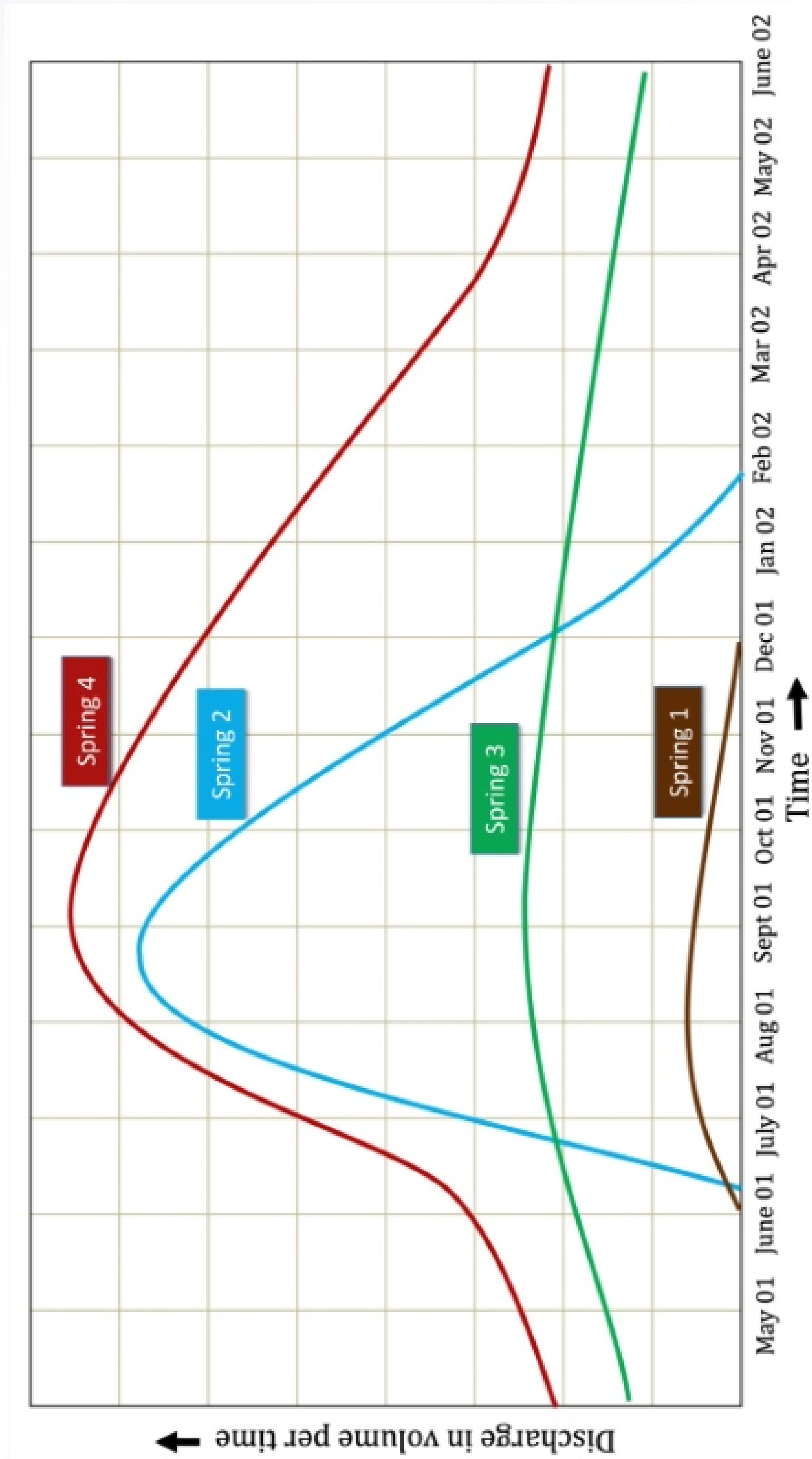


Fig. 9.1 Different components of a spring flow hydrograph

Point 'a' marks the commencement of discharge following a rainfall event, while the period between the onset of rainfall and the start of discharge, known as the starting time, is denoted as 't_s'. The time it takes for the hydrograph to reach its peak at point 'c' is referred to as the concentration time, labeled as 't_c'. The duration spanning from the point of maximum discharge until the hydrograph theoretically reaches zero at point 'e' is defined as the falling time, designated as 't_f'. Together, the concentration time and falling time constitute the base time of the hydrograph, referred to as 't_b'. The time gap between the centroid of the precipitation episode (C_p) and the centroid of the hydrograph (C_h) is termed the retardation time, represented as 't_r'.

The shape of the hydrograph is defined by its base (ae), the rising limb (ab), the crest (bcd), and the falling limb (de). The falling limb corresponds to the recession period. B and D are inflection points, where the hydrograph curve changes its shape from convex to concave and vice versa. In general, the part of the hydrograph from point d on is called the recession curve. In spring hydrology analysis of recession curve is most important which is characteristic parameter of any spring. Recession curve analysis helps to estimate the long lasting of any spring. The relatively flatter recession spring curve can last longer, therefore the purpose of any springshed programme has to focus on making spring recession curve flatter than the pre project rather than just to increase flow of spring at any time of measurement.

The distinctive shape of spring hydrographs indicates the transport and storage conditions in the aquifer. Since, spring discharge is the final results of various processes that governs the transformation of precipitation and other water inputs in the springshed into single spring output, it serves as the most reliable indicator for detecting any changes in the springshed area and spring characteristics. The shape of a discharge hydrograph depends on the size and shape of the drainage area, as well as the precipitation intensity. When a rainfall episode lasts longer and the intensity is lower, the hydrograph has a longer time base and vice versa. Intensive short duration storms cause sharp hydrographs with short time bases. The area under the hydrograph is the volume of discharged water from spring for the recording period. The retardation time or delayed response of the spring to water input and the shape of the hydrograph are first indicators of the recharge capacity and transmissive properties of the aquifer feeding the spring (Fig. 9.2). The information which can be derived from various shapes of hydrographs related to the characteristics of aquifer which feed the spring as well as recharge area which turns rainfall into aquifer storage are depicted in Table 9.1.



(Source: ACWADAM)

Fig. 9.2 Various shapes of spring hydrograph

Table 9.1: Information derived from the various spring hydrographs

Spring type	Description
Spring 1 (Seasonal Spring having low discharge)	• Storage capacity of aquifer which feeds the spring is limited. • Recharge area is very small and localized. • Revival of spring is not possible as storage is limited.
Spring 2 (Perennial Spring with variable discharge)	• Storage capacity of aquifer which feeds the spring is moderate. • Transmissivity of aquifer is high due to which infiltrated water is flush out. • Highly vulnerable spring towards to any changes in Land Use land Cover. • Good choice for the revival as spring's aquifer has moderate storage capacity.
Spring 3 (Sustained perennial spring)	• Spring's aquifer has good storage capacity. • Spring's aquifer has limited transmissivity due to which spring can last long. • Recharge area is far away from the spring outlet point. • Less opportunity to increase the discharge of spring as it has limited transmissivity.
Spring 4 (Perennial Spring with high discharge)	• Spring's aquifer has high storage as well as high transmissivity. • Such type of springs is very less in the country. • Most reliable for the rural water supply.

9.3.2 Spring flow variability

Variability represents the fluctuation in the spring discharge across the year. High variability represents the sensitivity of the springs towards the parameters which are responsible for the conversion of infiltrated rainfall into spring discharge. The springs having low variability are considered more reliable, therefore, the motive of any SSM programme is to reduce the variability in the spring discharge. There are number of the indexes such as index of variability (I_v), Meinzer variability index, and discharge variability ratio (DVR) which can be used to denote the variability of spring discharge.

One of the simplest means of determining the variability is to take the ratio of the maximum and minimum discharge to find the index of variability (I_v).

$$I_v = \frac{Q_{max}}{Q_{min}} \tag{9.1}$$

Springs having index of variability less than 2 ($I_v < 2$) are called constant or steady springs and are perfect choice for the reliable water supply. While springs having Index of variability greater than 10, are considered highly variable springs and are not the reliable source of water supply.

Meinzer (1923) proposed the following measure of variability expressed in percentage and described as:

$$\frac{Q_{max} - Q_{min}}{Q_{av}} \times 100 \tag{9.2}$$

Where, Q_{max}, Q_{min}, and Q_{av} are the maximum, minimum, and average discharge, respectively.

Normally Meinzer variability of a springs less than 25% (V<25%) are called constant or steady springs while greater than 100% (V>100%) are considered as variable springs.

Discharge variability ratio (DVR) is calculated as

$$DVR = \frac{Q_{10\%}}{Q_{90\%}} \tag{9.3}$$

Where, $Q_{10\%}$ is the high flow exceeded 10% of the time and $Q_{90\%}$ is the low flow exceeded 90% of the time. Different types of springs classified based on DVR is given in Table 9.2.

Table 9.2: Types of springs based on Discharge Variability Ratio

Spring Type	**DVR** $(\frac{Q_{10\%}}{Q_{90\%}})$
Steady (extraordinarily balanced)	1.0 - 2.5
Moderately (well) balanced	2.6 - 5.0
Balanced	5.1 - 7.5
Moderately unbalanced	7.6 - 10.0
Highly unsteady (extraordinarily unbalanced)	>10.0
Ephemeral	Infinite

The variability criteria based on DVR seems more realistic, as it has more sound hydrological background. However, its estimation needs daily discharge data of a spring for considerable period. Low value of DVR will be preferred for the spring to be used as a source for water supply.

9.3.3 Depletion time

The analysis of recession curve of spring hydrograph (Fig. 9.1) defines the flow regime of a spring. The recession curve characterizes the storage depletion or base flow from an aquifer during the period of zero or negligible precipitation/replenishment (Karanjac & Altug, 1980). The physical process of release of water from groundwater storage is a phenomenon that can be described by an exponential law, which is same as that used for base flow (Chow, 1964; Singh, 1988). One of the convenient ways to express the exponential law is:

$$Q(t+\Delta t=)\ Q(t)e^{-\frac{\Delta t}{t_0}} \quad (9.4)$$

Where, $Q(t)$ = spring flow at time 't' during recession, 'Δt' is the time increment and 't_0' is a parameter of the spring designated as depletion time and has the dimension of time. Depletion time is a characteristic parameter for a groundwater flow domain. It represents recession characteristic and depends on geology and geomorphology of a basin. It can be treated as a model parameter in mathematical models for spring flow. According to eq. 9.4, the variation of logarithm of spring flow with time is linear. The reciprocal of the product of negative of the slope of the straight line ($log_{10}Q \quad vs \quad t$) and 2.3, is designated as the depletion time in time units. A small depletion time (steep slope) indicates a small recharge area or high permeability and low porosity aquifer or a substantial groundwater abstraction or a combination of all or some of these factors. Whereas a high depletion time (flat slope) indicates a large dynamic storage or slow drainage or groundwater replenishment. Depletion time can be calculated for the spring flow series pre and post SSM programme.

9.3.4 Determination of depletion time

A spring hydrograph was plotted on a simple graph paper year wise using monthly spring flow data. After this recession portion was plotted on a semi-log graph paper (flow on log scale), which was fitted into a straight line (Fig. 9.3). This straight line was extendedin both directions to get the value of time axis for one log cycle. The time axis value of one log cycle was divided by 2.3, this would be the value of depletion time in months. Separate values of depletion time for different years can be estimated. Year wise depletion time values is good indicator to discuss the effect of various interventions in the recharge area of the spring.

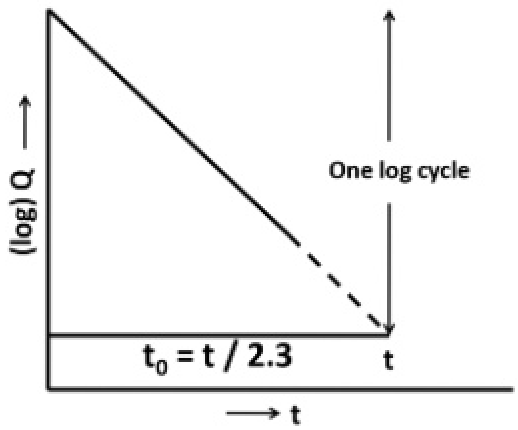


Fig. 9.3 Determination of depletion time

9.3.5 Aquifer recharge

The recharge of the aquifer of the catchment area of a spring is governed by several factors such as rainfall, geo-hydrologic characteristics (mainly permeability) of the material at ground surface, topography of the catchment, geo-hydrologic characteristics of the water bearing formation and geologic structure. Therefore, computation of recharge of a spring is a difficult phenomenon considering all these factors at a time. Aquifer recharge (AR) between the end of one dry season and the beginning of the next one can be estimated by the following equation with the aid of principle of continuity.

$$AR = Q_2 t_0 - Q_1 t_0 + \int_{t_1}^{t_2} Q\, dt \tag{9.5}$$

Where, 't_1' and 't_2' are the instances of time at the end of one dry season and the beginning of the next one, and 'Q_1', 'Q_2' are spring flow at time 't_1' and 't_2', respectively. The aim of any SSM programme is to increase the recharge of the springs during the rainy season so that spring should have sufficient storage available for continuously release the water even during the subsequent dry spell of the year.

9.4 Assessment of springshed programme: A case study of Sikkim state

To understand the utility of the above-mentioned parameters in assessment of any SSM programme, in fact how these parameters can be calculated from the observed data, a case study has been taken from the Dhara Vikas programme which was commenced during year 2008 to 2012 in the Sikkim State of India.

9.4.1 Study area and data used

Four springs viz. Karkharey Khola (SP1), Nun Thaley (SP2), Aita Barey (SP3) and Dhokung Dhara (SP4) which was taken under the Dhara Vikas programme by the Government of Sikkim for improving water security in the drought prone zone of the West district of Sikkim state have been selected to perform the hydrological analysis. These springs have a depression and fracture typology and are located in the lesser Himalaya in the 1100–1600 m elevation zone (Table 9.3).

Recharge area of these four springs were identified through hydro-geological investigation. Identified springsheds were then plotted on the cadastral map to designing the water conservation measures. Keeping in view of topography of the springshed both mechanical and vegetative measures were placed on the cadastral map. Mechanical measures comprise staggered contour trenches (SCT), drainage trenches on terraced field, loose boulder check dams, gabion, retaining wall, ponds, etc. While vegetative measure comprises grass plantation on SCTs bunds, live hedge row, plantation of horticulture/fuel and fodder tree, brush wood check dam, etc. Monthly rainfall and spring discharge data of one-year for pre- (2010) and post- (2011) springshed development programme were downloaded from www.sikkimsprings.org and analyzed. The basic parameters related to the studied springs are given in Table 9.4.

Table 9.3: Detailed information of springs selected for study

Spring Name (Code)		Karkharey Khola (SP1)	Nun Thaley (SP2)	Aita Barey (SP3)	Dhokung Dhara (SP4)
Spring Type		Fracture	Depression	Fracture	Depression
Location		27°12.114' N, 88°14.351' E	27°11.328' N, 88°13.860' E	27°11.341' N, 88°13.863' E	27°11.856' N, 88°18.028' E
Altitude ($m, amsl$)		1562	1604	1604	1192
Artificial recharge taken up	**Area (ha)**	5	5	5	7
	Volume (m^3)	222	152	454	349
Slope of recharge area (%)		30-40	30-40	30-50	<30
Land use of recharge area		Reserve Forest	Gaucheren	Gaucheren	Barren Land
Geology		Phyllite	Quartzite & Phyllite	Phyllite & Quartzite	Phyllite

Table 9.4: Various hydrological parameters estimated for 4 springs of Sikkim State for pre-and post- monsoon periods of springshed programme

Spring Name	Period	Iv (ratio)	V (%)	t_0 (month)	AR (m^3)	Increase in AR (%)	AR (% of rainfall)
SP1	Pre-	10.75	203.0	6.41	10039	98	12.79
SP1	Post-	6.56	148.7	13.04	19946	98	22.29
SP2	Pre-	16.76	209.5	4.24	19693	4	17.9
SP2	Post-	5.69	158.4	3.80	20477	4	16.3
SP3	Pre-	23.75	258.5	5.33	6803	133	8.7
SP3	Post-	8	160.0	7.39	15847	133	17.7
SP4	Pre-	14.5	177.7	9.13	18297	111	23.3
SP4	Post-	5.0	132.2	16.52	38593	111	43.1

Herein, various indexes of spring flow variability, depletion time and aquifer recharge are the main parameters for hydrological assessment of the impact of springshed development programme. These parameters were calculated for all 4 springs for pre- and post-implementation period of springshed development programme and compared. Variability, depletion time, aquifer recharge and aquifer recharge percentage of rainfall for all four springs (SP1, SP2, SP3, SP4) were calculated for the period of post-springhshed development programme (year 2011) and compared with the corresponding values of pre-springshed development programme period (year 2010) (Table 9.4). It can be seen from Table 9.4 that the index of variability (I_v) has decreased significantly and comes under 10 in all cases. Worth notice is $I_v > 10$, indicative of highly variable spring. Furthermore, Meinzer spring flow variability is also significantly low in all the springs, especially for SP3 in which spring flow variability decreased by ≈100% (from 258% to 160%). Depletion time for SP1, SP2, SP3, and SP4 were estimated for post springshed development programme and it was observed that depletion time increased significantly for all springs (except SP2). Fig. 9.4 showing recession flow curve for year 2011 became flatter than year 2010, indicating increase in depletion time as a result of springshed development programme.

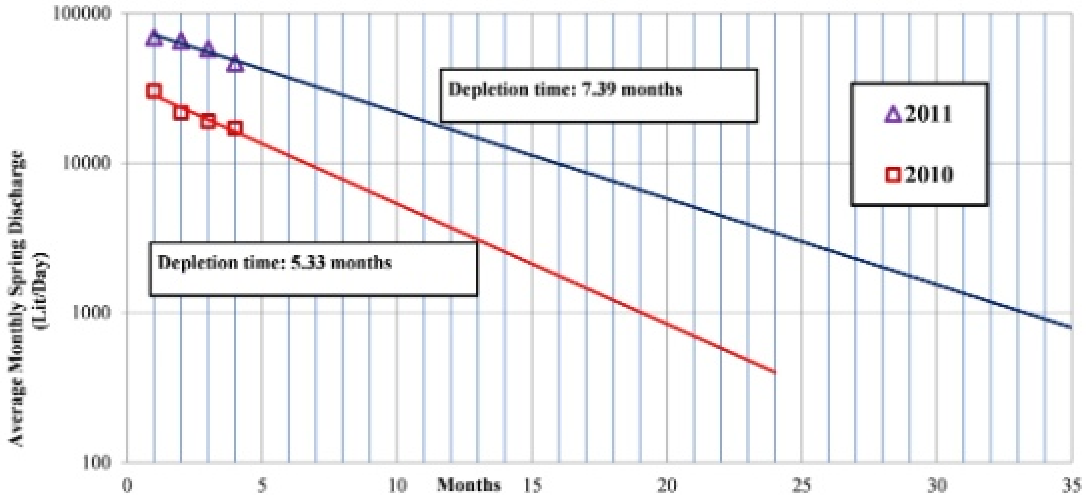


Fig. 9.4 Change in depletion time for Aita Barey (SP3) spring during pre- and post-springshed development programme

It can be seen from Table 9.4 that depletion times have increased in all springs except SP2. Herein, only one-year data has been used, which is not sufficient to see the impact of artificial recharge works especially when springs have large recharge areas and dominated by barren land like in the case of SP2. From the available spring flow data and calculated depletion times (t_0), aquifer recharge taken place during monsoon season of year 2010 and 2011 were calculated for all springs and presented in Table 9.4. Aquifer recharge increased by 98%, 4%, 133% and 111% for SP1, SP2, SP3, and SP4, respectively. It is notable that only 14% increase in the rainfall occurred during the monsoon season (May-August) in year 2011 as compared to year 2010. Rainfall contribution to recharge of the aquifers increased from 12.79% to 22.29%, 8.7% to 17.7%, 23.3% to 43.1% for SP1, SP3, SP4, respectively. However, no significant increase in aquifer recharge was observed in case of SP2. Evidently, in all the springs except SP2, rainfall has contributed more to groundwater recharge after placement of artificial recharge measures in the identified recharge area of the springs.

9.5 Assessment of minimum storage requirement for sustainable use of spring water

To make the studied springs dependable sources for the local populace across the year, assessment of minimum storage is a good practice. By storing the water volume equal to the minimum storage will certainly help to manage the spring water efficiently. In this approach the surplus water during the peak period of spring flow can be stored to meet the excess demand of dependent population during the lean season of the year. In this regard, minimum storage requirement was calculated by the linear calculation of demand-supply and presented in tabular form in Table 9.5 for spring SP3. Minimum storage requirements were estimated for post- and pre-periods of implementation of the springshed development project so that the effect of springshed programme can be clearly visualized. The data presented in Table 9.5 reveals that, from January to May (a span of 5 months) in the year 2010, demand consistently exceeded the available inflow. Consequently, this surplus demand for water had to be periodically addressed through storage solutions. The maximum value of cumulative excess volume represents the minimum storage necessary to fulfill the demand. The storage requirement for the present case was estimated to be 1266 m^3 for the year 2010. After the springshed development program, the minimum storage requirement significantly reduced to only 280 m^3 in 2011, and the dry period decreased from 5 months to 3 months due to augmentation of spring flow and its longevity. Consequently, providing a storage tank with a capacity of 280 m^3 would aid in meeting the demand by storing the water. The storage tank would begin refilling in April and be completely filled by mid-May. From April to December, there would be a surplus of water availability compared to the demand.

Table 9.5: Estimation of minimum storage requirements for SP3 (Aita Barey) spring

Month	Spring flow volume (m^3)		Demand volume (m^3)	Excess water (col. 3 – col. 2)		Cumulative excess demand		Cumulative excess inflow volume	
	Pre 2010	Post 2011		Pre 2010	Post 2011	Pre 2010	Post 2011	Pre 2010	Post 2011
Jan	216	367	403	-187	-36	187	36	-	-
Feb	129.6	302	403	-273	-101	461	137	-	-
Mar	86.4	259	403	-317	-144	777	280	-	-
Apr	57.6	432	403	-345	29	1123	-	-	28.95
May	259.2	763	403	-144	360	1266	-	-	389
Jun	820.8	1354	403	418	951	-	-	418	1340
Jul	1368	1973	403	965	1570	-	-	965	2909
Aug	907.2	2074	403	504	1671	-	-	1469	4580
Sep	648	1966	403	245	1563	-	-	1714	6143
Oct	568.8	1735	403	166	1332	-	-	1880	7475
Nov	511.2	1390	403	108	987	-	-	1988	8461
Dec	511.2	994	403	108	591	-	-	2096	9052

Note: Demand volume was estimated by assuming @55 *lpd* for human, 20 *lpd* for cow, 20 *lpd* for bullock, 4 *lpd* for goat and 10 *lpd* for pig.

The minimum storage requirement for SP2 spring was calculated as 11.55 m^3 before the implementation of springshed programme. After the implementation of springshed program, the increased discharge became sufficient to meet the local demand, rendering any minimum storage unnecessary. In the case of SP4 (Dhokung Dhara) spring, the storage requirement has been estimated to be 2303 m^3 and 990 m^3 during the year 2010 and 2011, respectively. For SP1 (Karkharey Khola) spring, excess of demand over the spring inflow for 8 months in the year before springshed development program making the implementation of minimum storage infeasible. However, after artificial recharge in the spring catchment, dry period was reduced from 8 months to 5 months and a minimum storage of 2269 m^3 was sufficient to make this spring a sustainable water source for local households.

9.6 Sustainability

The sustainability of spring discharges depends on geology, land use, slope, morphology, and meteorological parameters. Factors such as encroachment in the catchment area, variations in the climate parameters, etc., have adversely affected the discharge from springs. Rawat et al. (2018) proposed that a spring can be considered as sustainable source of water in a particular region if its flow can last (i.e., depletion time) longer than the most prolonged driest spell in the region. Therefore, sustainability of any spring is not only governed by its magnitude and longevity, but also on the pattern of rainfall in the area. To understand the sustainability of springs in different parts of the IHR nine springs in different parts of IHR (02 springs from north-western IHR i.e., Jammu & Kashmir, 03 springs from western IHR i.e. Uttarakhand, and 04 springs from north-eastern IHR i.e., Sikkim) were selected for the study (Rawat et al., 2018). Depletion times were estimated 6.96, and 6.52 months for two springs of north-western IHR; 2.50, 1.09, and 5.22 months for the three springs of Western Himalayas; 6.41, 4.24, 5.33, and 9.13 months for four springs of north-eastern IHR. Driest spells of different parts of the country were estimated by Singh & Ranade (2010) using the rainfall data for the period of 1951-2007. They found the driest spell for the Western Himalaya and the Eastern Himalayas were 156 days (5.2 months) and 80 days (2.7 months), respectively. Therefore, based on the estimated depletion time and the driest periods in the respective regions, it can be concluded that Western IHR springs are not sustainable as they have shorter depletion time than the period of driest spell in the region. However, the springs in the north-western IHR springs are currently sustainable but require future attention. Regarding depletion time, north-eastern IHR springs are reliable due to the shorter dry spell in the region, i.e., 2.7 months, but they also require attention due to their high variability and low values of minimum flow.

9.7 Conclusion

In the present chapter, different hydrological parameters such as spring flow variability (Index of variability, I_v; Meinzer variability, V; Discharge variability ration, DVR); Depletion time; Aquifer recharge were used to assess the impact of any SSM programme through an example of Dhara Vikas Progrmme implemented by Rural Management & Development Department (RMDD), Sikkim during 2008-12. It is also demonstrated to assess the minimum storage requirement to make the dependable source of small flow of springs. In this way the dependability of the springs can be improved by creating minimum storage, as demonstrated for the Sikkim springs, to meet local water demand during the lean season of the year. Sustainability of any spring was explored in terms of its capability to check the driest spell in the region. Last but not least the accuracy in the impact assessment of any SSM programme eventually depends upon the availability of pre and post hydro-metrological data of the spring/springshed, therefore it is suggested the agencies dealing with SSM programmes to gauge the various hydro-metrological parameters in the springshed.

Chapter 10

Impact Assessment in Springshed Management

10.1 Background

Although impact assessment is the last step in SSM, it holds utmost importance in the entire process of spring rejuvenation. This largely depends on the baseline surveys in springshed management projects, which cover aspects like spring discharge, water quality, and socioeconomic factors. The present chapter aims to outline both short-term and long-term impacts, categorizing them into ecological, economic, social, and sustainability aspects, each with specific indicators and verification methods. It is imperative to discuss all those parameters that need to be collected from the beginning to the end of SSM. Hence, this chapter emphasizes the need for ongoing monitoring and simultaneously provides a detailed framework for assessing the effectiveness and sustainability of springshed management initiatives.

10.2 Baseline surveys

Before starting a new project, it is best to analyze the initial state of things in the project area. Hence, a baseline survey is done to get a detailed assessment of the project area regarding spring discharge, biomass productivity, etc. In the case of SSM, the following baseline surveys can enhance the understanding of the results obtained from the project.

(i) **Spring discharge:** The discharge of spring, also called its flow, is the volume of water passing a certain point during a certain time. Measuring spring flow is a way of characterizing a spring's overall condition, which also showcases the need for treatment of the spring. In most of the countries in the word it is normally measured in cubic feet per second (CFS) or in million gallons per day (MGD) or gallons per minute (GPM), however, majority of the springs in India are characterized by small flow, it is suggested to measure the spring flow in liters per minute (LPM). The spring discharge data needs to be taken weekly to bi-weekly basis.

(ii) **Spring water quality:**
The survey of the spring water quality is required only if the water of the spring is utilized by the community for household consumption. The spring water quality data needs to be recorded seasonally. Majorly 3 components are checked for the water quality of the spring, these are pH, TDS (Total Dissolved Solids), and fecal.

(iii) **Household surveys- consumption, livestock productivity, health, and women's drudgery:**
A household survey is required only when the spring water is used by the villages, either for agriculture or household activities. In such a case, the household survey before and after the intervention can be beneficial to check for the effectiveness of the program.

(iv) **Biomass productivity:**
Biomass productivity refers to the grass productivity in the forest area. The survey of biomass productivity before the intervention is made is an important baseline survey in the case of the SSM project.

(v) **Agricultural productivity:**
Agricultural productivity refers to the crop productivity. The survey of agricultural productivity before the intervention is made is an important baseline survey in the case of the SSM project. However, this should be applied only when the spring water is used for agriculture.

10.3 Impact of the SSM project

The overall impact of the SSM program is both short-term and long-term. The short-term benefits of SSM include an increase in biomass productivity, a decrease in soil erosion, increase in the water table and soil moisture. In the long term, the water quality of the spring improves, and the discharge also increases. Four major indicators as depicted in Fig. 10.1 can be considered for estimating the impact of the SSM project. These indicators are discussed as below:

Fig. 10.1 Major indicators for estimating the impact of a SSM project

10.3.1 Ecological impact

The major objective of the SSM activities is ecological conservation and maintenance. Springs are the lifeblood of the forest; hence it is very important to maintain it. The impact of SSM on the ecology can be monitored using the following indicators and summarized in Table 10.1.

(i) **Spring discharge:**
Proper implementation of the SSM program can help increase spring discharge, that is, the volume of water passing a certain point during a certain time. The increase in the discharge of a spring can be verified by comparing the spring discharge data collected before and after introducing the interventions. A register can be maintained for noting down such data in order to keep it in organized manner.

(ii) **Water quality:**
After the proper treatment, the water quality of a spring can be a good indicator

of the success of the springshed project implemented in an area especially when spring water is being used for household activities such as cooking and drinking. An improvement in the water quality can help in improving the health of the communities that are directly or indirectly dependent on the spring. The improvement in the water quality of a spring can be verified by comparing the water quality data collected before and after introducing the interventions. A register can be maintained for noting down such data in order to compile it for comparison and future study.

(iii) **Soil moisture:**
Appropriate SSM intervention helps in increasing the soil moisture content, hence, acting as an important monitoring indicator. The increase in the moisture content of the soil can easily be determined by comparing the scientific moisture content data of the soil collected before and after the interventions are made. With the help of accurate soil moisture sensor such as Time-Domain Reflectometry (TDR) probes, the soil moisture can be measures instantly at any desired depths.

(iv) **Biomass productivity:**
The increase in biomass productivity is a key monitoring indicator for the SSM programme. An increase in biomass production indicates an effective program implementation. It can be verified by comparing the biomass survey data collected before and after the introduction of the interventions for SSM.

(v) **Soil erosion:**
Soil erosion can reduce to a great extent as SSM interventions prevent soil and water runoff in mountainous areas. Hence, it is a key indicator to monitor the impact of the springshed program. Scientific data collected can be compared before and after the interventions are made in order to verify the indicator.

Table 10.1: Monitoring indicators and their means of verification for assessing the ecological impact of a springshed programme

Monitoring Indicators	Means of Verification
Spring discharge	Springs flow – pre and post-data of spring flow series at least monthly scale (Register to be maintained)
Water quality	Spring water quality – pre and post-data at least basic water quality parameters (16 parameters) as suggested in the framework document of operational guidelines for the implementation of Jal Jeevan Mission (JJM) in the light of safe drinking water quality standards (IS 10500:2012) (Register to be maintained).

Soil moisture	Scientific data collected – pre and post using TDR probes at various soil depths.
Biomass productivity	Biomass Survey data collected – pre and post
Soil erosion	Scientific data collected – pre and post

10.3.2 Economic impact

The economic impacts of SSM can be analyzed using various indicators. The economic impact of the springshed can be more useful for the community dependent on the spring that is been treated. The following monitoring indicators can be used to analyze the economic impact of the SSM program.

(i) **Per capita increased availability of drinking water:**
SSM helps in increasing the availability of drinking water by increasing the spring discharge and improvement in the water quality of the springs. This indicator can be verified through the pre and post household water consumption survey.

(ii) **Fodder availability and increased production of livestock:**
SSM results in an increase in agricultural productivity. This helps in the increased availability of fodder for the cattle, which will ultimately result in increased productivity of the cattle. Pre and post-intervention household surveys can help in verifying this indicator.

(iii) **Enhanced agriculture productivity:**
As mentioned above, the interventions of a springshed development program help in increasing the agricultural productivity of the springshed area. This indicator can be verified through household surveys. Comparison of pre and post intervention crop harvesting data can also be used to verify this indicator.

Various monitoring indicators which are helpful to assess the economic impact of a springshed programme and their means of verification are given in Table 10.2.

Table 10.2: Monitoring indicators and their means of verification for assessing the economic impact of a springshed programme

Monitoring Indicators	Means of Verification
Per capita increased availability of drinking water	Household water consumption survey – pre and post
Fodder availability and increased production of livestock	Household surveys –Pre and Post.
Enhanced agriculture productivity	Household surveys and Crop Harvesting Data –Pre and Post

10.3.3 Social impact

The social impact of any project is one of the most important aspects of any project since it helps benefit the community and hence ensures their participation to a large extent. Community involvement is an essential piece in the puzzle of forest conservation. Since, in most of the cases springshed lies in the van panchayat region, involvement of local community can help the forest department in their projects. Furthermore, village communities can get benefitted and be empowered by the interventions of SSM. The following indicators can be checked to ensure the impact of SSM on the communities:

(i) **Better health indicators due to better water quality:**
Treatment activities during SSM results in a better quality of the spring water. This will in turn have a positive impact on the health of the communities dependent on the spring for their drinking water requirements. This impact can be verified by comparing the health records of the region pre and post SSM interventions. Participatory Rural Appraisal (PRA) activities and household surveys can also be performed to verify this indicator.

(ii) **Reduction in the drudgery of women:**
Women are the ones most affected by the unavailability of water since they are responsible to collect water for household chores. They have been forced to walk long distances to get water for the family's daily needs and hence they are used to compromise their lot of time from their daily routine. Recharge of water sources near their house can save their time as well as reduce their drudgery. This indicator can be verified through a comparison of women's conditions pre and post intervention PRA activities and household surveys.

(iii) **Per capita water accessibility:**
With an increase in the spring discharge, the per capita availability of water will also increase. This will help people lead a healthier lifestyle. This indicator can be verified through PRA activities and household surveys, by comparing the responses before and after the introduction of the interventions of SSM.

(iv) **Participation of weaker sections of society and women in institutions:**
By ensuring the participation of institutions such as the van panchayats for springshed development can help in their empowerment and ensure comprehensive decision-making and easy implementation work. Local community members can also be included in the project. Local community members can be included in the decision-making process in order to make the process participative. This will give the community members a sense of responsibility towards the work done for SSM and will be motivated to maintain the water source. This can be ensured by maintaining meeting registers containing the attendance and profile of the attendees along with the details of monthly meetings.

Various monitoring indicators which are helpful to assess the social impact of a springshed programme and their means of verification are given in Table 10.3.

Table 10.3: Monitoring indicators and their means of verification for assessing the social impact of a springshed programme

Monitoring Indicators	Means of Verification
Better health indicators due to better water quality	PRAs, Household Surveys, and Health Records –Pre and Post
Reduction in the drudgery of women	PRA s and Household surveys –Pre and Post
Per capita water accessibility (to measure the equitable distribution systems)	PRAs and Household Surveys –Pre and Post

10.3.4 Sustainability of the program

Once the SSM program is successfully implemented, it becomes more important to sustain or maintain the springs. This can be possible only through community and ground staff participation. Following are few indicators necessary to ensure the sustainability of the program:

(i) **No. of cadre trained in springshed development and their knowledge level:**
A cadre should be trained and maintained in every department dealing with SSM programme in order to look after SSM and its maintenance. Local community members should also be trained in order to ensure participative SSM. The impacts of these trainings to department staff as well as community members should be assessed, in order to make improvements in the same.

(ii) **Strong village-level institutions – social actions, participation:**
After successfully implementing the SSM program, it is important to sustain the implemented work in order to reap long-term benefits. Village level institutions can be built in order to sustain the work done under the SSM program. Such institutions will ensure community participation for sustaining the SSM program. Case studies can be prepared on social or collective action by communities to assess the impact of institutionalization.

(iii) **Roadmap for future springshed development:**
The springshed development plan prepared and implemented in the present can help in designing a roadmap for the future springshed development plans. This will help the department to identify problems and make changes to the plan based on past experiences. Impact assessment and consultative meetings can be held to point out the loopholes or bottlenecks in the previous plan and make alterations in the upcoming springshed development plan.

Various monitoring indicators which are helpful to ensure the sustainability of a springshed programme and their means of verification are given in Table 10.4.

Table 10.4: Monitoring indicators and their means of verification for assessing the sustainability of a springshed programme

Monitoring Indicators	Means of Verification
No. of cadre trained in Springshed development and their knowledge level	Impact assessment (impact of trainings to be assessed here)
Strong village level institutions – social actions, participation	Case studies on social/collective action by communities
Roadmap for future springshed development	Consultative meeting, Impact assessment studies

10.3.5 Monitoring and verifying mechanisms

(i) **Spring/stream discharge:**
Spring discharge data is the volume of water passing a certain point during a certain time. The discharge should be taken on a monthly basis before as well as after the implementation of SSM program. This can be noted down in a register or in the computer to compare the results before and after implementation of the SSM program.

(ii) **Water quality:**
The water quality data checks for the contamination in the water. Its measurement is required only if the water is used for drinking and household activities. It must be performed seasonally. The pre and post implementation data can help to analyse the effects of SSM program on the particular spring.

(iii) **Biomass productivity – pre and post project:**
The biomass productivity should be measured in both, the recharge area as well as the command area for adequate plot sizes, as shown in Fig. 10.2 diagonally through the area. The productivity of these plots is then measured before as well as after (2-3 years after) the implementation of the SSM program. NDVI derived from remote sensing images can be used to extract the biomass productivity of the springshed for redefined fixed dates during pre and post project period. This data can now be analysed and compared by placing it in a table (Table 10.5).

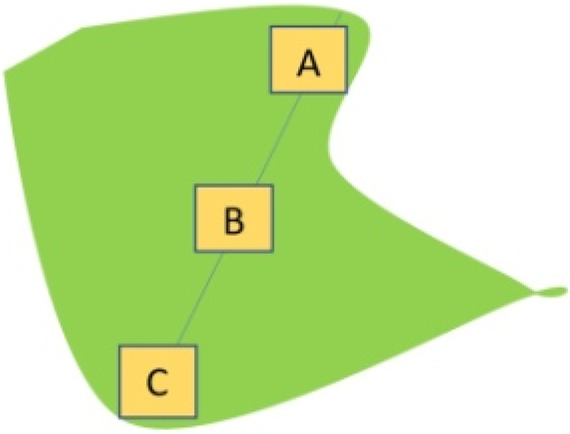


Fig. 10.2 Identification of plots for measurement of biomass productivity for predefined fixed dates during pre and post project period

Table 10.5: Estimation of biomass productivity at different locations for predefined fixed dates in the catchment during pre and post springshed programme

Location	Pre Springshed Management					Post Springshed Management				
	Plot A	**Plot B**	**Plot C**	**Avg.**	**Gross Productivity (t/ha)**	**Plot A**	**Plot B**	**Plot C**	**Avg.**	**Gross Productivity (t/ha)**
Recharge Area										
Spring 1										
Command Area										

Table 10.6: Estimation of biomass productivity at different locations for predefined fixed dates in the catchment during pre and post springshed programme

Location	Pre Springshed Management										Post Springshed Management									
	Plot A		**Plot B**		**Plot C**		**Avg.**		**Gross Productivity (t/ha)**		**Plot A**		**Plot B**		**Plot C**		**Avg.**		**Gross productivity (t/ha)**	
Command Area	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S
Crop 1	G	S	G	S	G	S	G	S	G	S	G	S	G	S	S	G	S	G	S	G

(iv) **Soil moisture:**
The soil moisture data should be collected through the scientific method for predefined dates and depths before the implementation of the project and then one year after the implementation of the SSM project. These data can be compared in order to analyse the impact of the springshed program on the soil moisture content.

(v) **Drinking water availability:**
This verifying mechanism is valid only when the spring water is used by the community for drinking. Household surveys and PRAs are effective tools to observe the change in the availability of drinking water due to the SSM program.

(vi) **Livestock productivity:**
Livestock productivity is linked to the fodder available. SSM can help increase the availability of fodder and hence can increase the livestock productivity. This increase can be observed only after 5 years of project implementation through household survey.

(vii) **Agriculture productivity:**
The agricultural productivity should be measured in both, the recharge area as well as the command area by cutting adequate plot sizes, as like biomass productivity, diagonally through the area. The productivity of these plots is then measured before the project as well as after (2-3 years) the implementation of the SSM program. The productivity of grain and straw should be measured separately. This data can now be analysed and compared by placing it in a table (see Table 10.6).

(viii) **Heath conditions:**
SSM can help in making clean drinking water available to the community which will in turn result in improvement in the health condition of that community. This can be analysed through comparing the responses received from the household survey after 1 year as well as before implementing the SSM plan.

(ix) **Women's drudgery:**
Women are the most affected community when it comes to scarcity of water since they are the ones who are responsible to arrange water for the household chores. Hence, if the spring is benefitting the community, it will have the most positive impact on the women. This can be analysed through household surveys, pre and post implementation of SSM program.

(x) **Social and gender equity:**
Since the women are the most affected from the scarcity of water, SSM can

increase the availability of water and hence reduce the drudgery of women, which will lead to their empowerment. Increased water availability will also allow all sections of the society to get access to water equally, hence leading to social and gender equity. The impact of SSM program on the social and gender equity can be measured and analysed through PRAs and household surveys, pre and post implementation of SSM program.

Frequency of measurement of indicators used for verifying mechanism is given in Table 10.7.

Table 10.7: Timing of measurement of indicators used for verifying mechanism

Indicators for verifying mechanism	When to be checked for
Spring discharge	weekly to bi-weekly basis
Water quality	seasonal basis
Biomass productivity	after 2-3 years
Soil Moisture	after 1 year
Drinking water availability	through household surveys
Livestock productivity	after 5 years, through household surveys
Agricultural Productivity	after 2-3 years
Health condition	after 1 year, through household surveys
Women's drudgery	through household surveys
Social and Gender Equality	PRA and household surveys

Chapter 11

Capacity Building in the Field of Springshed Management

11.1 Background

Springs are the lifeline of mountain and hill ecosystems, as more than one-third of the population residing in these regions are directly dependent on springs for their water requirements, and many more are indirectly dependent on them. However, climate change, seismic and other anthropogenic activities have led to the depletion of these underground aquifers. There is a need for spring revival to meet the water requirements (related to drinking, washing, bathing, agriculture, etc.) of the local communities. Springs also play a crucial role in sustaining the local biodiversity.

It is envisaged that integrating concepts and approaches into actions based on the six steps methodology of SSM, especially in the mountain regions of India has become crucial for the water security of these regions. The successful implementation of flagship programs like PMKSY, JJM, MGNREGS, Amrut 2.0, Natural Farming (including Millets Mission), and VVP especially in the hill and mountain ecosystems, also depends on effective spring revival activities. The participatory-based spring revival practices will play a critical role in achieving Sustainable Development Goals (SDGs) 1, 3, 5, 6, 10, 12, 13 and 15.

Recognizing the significance of springs in the hill and mountainous ecosystem and their role in fulfilling regional water requirements, the Department of Water Resources, River Development & Ganga Rejuvenation (DoWR, RD & GR) under the Ministry of Jal Shakti, Government of India, has acknowledged the necessity of establishing a concrete mechanism for SSM across the country through various state and centrally funded schemes. Consequently, the Department established a Steering Committee on 'Springshed Mapping of the IHR, including mountainous regions of the country, and Springshed-based Watershed Management Plan' to develop a SOP for initiating spring and springshed mapping throughout the country.

The core committee members designated for the Capacity Building component have gone ahead and collected and collated the views of different stakeholders across the country involved in SSM. The information has been further analyzed by the committee to cover various aspects of capacity building including challenges encountered in SSM, gaps in skills of various stakeholders, mechanisms for effective capacity building, and required IEC materials for capacity building, which have been put together in this note.

Spring revival needs a multi-disciplinary team (consisting of geo-hydrologists, engineers, ecologists, social scientists, etc.) with required skills for the various stage of planning, implementation, and monitoring. Hence there is a need for capacity building across a wide spectrum of stakeholders – from community resource persons to policy-level decision makers in a strategic manner. There is a need to build and strengthen the capacities of various functionaries involved in SSM, under various programs, on three aspects:

(i) **Concept:** The concept of 'springshed' is often misunderstood and confused with the sister terms such as watershed. Hence, it is important to understand the concept of 'springshed' in order to carry out activities in the desired area that can successfully revive springs.

(ii) **Approach:** It is important for the team involved in the SSM activities to be thorough with the approach i.e., the six-step methodology for sustainable results.

(iii) **Strategies:** Area specific strategies need to be adopted for spring revival considering the land use, land cover, land ownership, soil depth, soil type, needs & willingness of the users, and governance system.

Springs are local resources that have been used by the communities for generations. Hence, demystifying science, decentralizing decision-making, and participatory action around spring through capacity-building activities for concerned functionaries is increasingly important for spring revival and maintenance. Integration of traditional knowledge and modern technologies can help in the spring revival activities. Community-based monitoring can further enable decision making for the sustenance of the spring revival activities in the long run.

There is a need to identify experienced capacity-building institutions and bring them together for undertaking joint capacity-building activities. The training modules should be developed based on the 6-Step methodology for the different stakeholders considering their roles and responsibilities. Training materials in different languages need to be prepared covering various aspects of springhsed management for the wide spectrum of stakeholders.

11.2 Methodology

The Core Group members consulted various agencies involved in different aspects of SSM at the state and/or national level. These included NGOs, Government Departments, and Academic Institutions (Annexures 1.1 and 1.2). The consultations have been in the form of meetings, workshops and personal interviews. It included the following points:

(i) Role of the organization/institution in SSM
(ii) Geographical coverage
(iii) Personnel involved in SSM and their specific roles
(iv) Challenges encountered by the personnel
(v) Current sources of capacity building
(vi) Capacity building needs

Most of the organizations were found to be involved in the implementation of SSM which are either sponsored by various government flagship programs (like JJM, PMKSY, watershed development, MGNREGS, etc.) or supported by CSR. The main capacity-building Institutions include ACWADAM, PSI, CHIRAG, and PRASARI. Some state ATIs are also undertaking training and capacity building programs.IIT-R, GBP-NIHE, CGWB, and NIH is mainly involved in research work, especially related to spring inventory, hydrological modeling and recharge area identification. Arghyam has contributed to the development of various digital IEC materials with the help of ACWADAM and PSI.

The role of the different functionaries involved in various SSM programs along with challenges faced by them helped in identifying the various capacity building needs. Based on the consultations and views expressed by different stakeholders involved in SSM and capacity building institutions, capacity building in SSM may be dwell upon following four sections:

- Identified challenges: Issues for capacity building
- Stakeholder wise identified gaps for capacity building
- Mechanisms for effective capacity building
- Capacity building materials

11.2.1 Identified challenges: Issues for capacity building

The following challenges have been identified in springshed based watershed management which needs to be addressed through capacity building of concerned stakeholders.

(i) **Lack of awareness & capacities:**
There is a lack of awareness about springshed concept and required skills (related to planning, implementation, and monitoring) among people involved in SSM at all levels i.e., Gram Panchayat, Govt. and Non-Govt. functionaries, and at decision-making levels. Such lack of awareness leads to inappropriate designing of programs, and faulty approaches and strategies in SSM.

(ii) **Undermined role of springs in pipeline water supply:**
In the past few decades when the centralized piped water supply has reached the households in the mountainous and hilly areas, the relevance of the spring water has been declining. There is a lack of awareness among the people, about the role of springs in contributing to the pipeline water supply. There is a need to make all stakeholders aware of the contribution of springs to base flows of streams, usually tapped for piped water supply.

(iii) **Need for simplification of spring science:**
Most functionaries expressed difficulties in understanding the hydrogeology of springs for the demarcation of recharge areas. The other areas of difficulty include creating a spring inventory, measuring water quality, designing treatment measures, etc. There is a need to demystify spring science so that scaling of SSM can be undertaken. Representatives of communities need to be trained as para hydrogeologists so that they are able to undertake monitoring of spring discharge and water quality. Similarly, extension functionaries need to understand the hydrogeology of springs and context specific treatment measures.

(iv) **Absence of water budgeting and demand management:**
Most of the focus of current efforts is on enhancing the spring discharge without

taking into consideration the water demand (domestic and agricultural) of the concerned community and accounting for other water resources. The practice of water budgeting should be carried out through participatory water resource assessment. It is also necessary to integrate demand management measures along with SSM for sustainable results. Hence, the concerned personnel need to be trained on water budgeting as well as demand management measures.

(v) **Limited application of hydrogeology:**
Many functionaries tend to apply watershed approaches while identifying recharge areas and treating springs, since they lack a proper understanding of the hydrogeology. SSM is a technical process requiring the involvement of trained hydrogeologists for proper mapping, monitoring, and characterization of the concerned aquifers.

(vi) **Gaps in connecting recharge interventions with livelihood activities:**
Springs recharge activities are often conducted in isolation and not clubbed with livelihood activities such as plantation and orchard development. Clubbing spring revival activities with livelihood development activities can motivate the community to participate in SSM activities to take multiple benefits like fuelwood, fodder, fruits, medicinal plants, etc.

(vii) **Lack of context-specific protocols for spring revival:**
The protocols for the revival of the springs are needed to be tailor-made as there is no one size fit for protocols when it comes to conducting SSM activities in any area. Hence, trained personnel are needed to understand the local situation and dynamics to develop context-specific protocols for spring revival.

(viii) **Limited understanding of water and sanitation linkages:**
SSM activities in the concerned recharge area generally tend to overlook sanitation practices resulting in poor water quality. Efforts should be made to include proper sanitation practices in SSM practices such as the prohibition of open defecation and grazing by stray livestock. This will help in keeping the recharge area clean maintaining the water quality of the aquifer.

(ix) **Lack of incentives for para hydro-geologists:**
People trained as para-hydrogeologists do not receive adequate incentives, especially in post project phase, thereby affecting the regular monitoring of spring discharge and water quality. Incentives can encourage para-hydrogeologists to take on SSM activities and ensure sustainability in the efforts.

(x) **Absence of Decision Support System:**
The policy makers highlighted the absence of a decision support system which

would otherwise be helpful for the concerned functionaries to take appropriate actions at different stages of SSM.

(xi) **Lack of training materials in local languages:**
The training material developed for SSM is presently available mostly in English. However, India, being a land of many languages and dialects, efforts should be made to develop training manuals in various languages in order to make the content understandable and interesting for the local communities.

(xii) **Limited sharing of monitored parameters for decision-making:**
Presently most of the data collected (pertaining to rainfall, spring discharge, and water quality) is accessible to the concerned researchers. It is felt necessary to analyze the data collected and shared with the local communities in a simplified manner to facilitate community-based decision making.

(xiii) **Shortage of dedicated human resources and capacity-building institutions:**
Most of the institutions shared that there is shortage of skilled personnel who could be committed to SSM activities. At the same time, only few institutions exist who could impart training to the concerned personnel for SSM.

11.2.2 Stakeholder wise identified gaps for capacity building

The personnel involved in SSM programs can be broadly categorized into the following four groups, namely.

(i) Community level institutions including gram panchayats, village water and sanitation committees, Women's Groups (Mahila Mangal Dals, and Mahila Madals), and Water User Groups, are mainly responsible for the operation and maintenance of springs.

(ii) Para workers (also known as Jal Praharis/Sevaks) including representatives of communities who are mainly responsible for community mobilization, microplanning, monitoring of spring discharge and water quality, and extending support in treatment measures.

(iii) Extension agencies include personnel from both government and non-government organizations who are involved in spring inventory preparation, identification of critical springs, setting up governance systems, establishing monitoring mechanisms, and impact assessment.

(iv) Policy/Decision makers include the higher-level authorities in different government departments who are responsible for planning SSM programs, personnel hiring and capacity building arrangements, and monitoring and evaluation.

Further, there is need for capacity building of researchers including field researchers which need training in advance tools and methods for improving the methodology for springshed mapping and quantification, scenario building and modeling under changing climate and social conditions. The six-step methodology of SSM include:

(i) Comprehensive Mapping of Springs and Springsheds
(ii) Setting up a Data Monitoring System
(iii) Understanding Social and Governance Systems of Springs
(iv) Hydrogeological Mapping, development of conceptual layout and identification of recharge area
(v) Developing SSM and governance protocols
(vi) Measuring the impacts of spring revival activities

The functions of the identified stakeholders' groups in each step of the six-step methodology of SSM was further detailed to understand their challenges and capacity-building needs. These are summarized in Annexure 11.1. These issues need to be addressed while developing training modules and materials for the stakeholders. Annexures 11.2(A) to 11.2(D) are examples of training modules designed for the four groups of stakeholders which can be further fine-tuned according to the requirements. Pedagogy should include classroom lectures, group discussions, practical exercises & field exposure.

11.2.3 Mechanisms for effective capacity building

Capacity-building strategies need to take into account following:

(i) **Identification a consortium of training institutions and experts:** A national/state-level portal for SSM is required which having a database of not only springs but also capacity-building institutions. Since SSM is a multidisciplinary exercise, there is a need to identify institutions and individuals having the required expertise in different fields. These individuals and institutions need to come together to impart training to a range of stakeholders.

Training workshops at national and regional levels can be beneficial for the planning, executing, and monitoring agencies.

(ii) **Development of training modules and IEC materials in local languages:**
It is important to develop training modules for various stakeholders based on the six-step methodology for SSM, considering their roles and responsibilities. A cadre of master trainers through the Training of Trainers module needs to be further prepared for imparting training at the community level. Training materials should be developed in the local languages in the form of posters, manuals, handbooks, and monographs in order to make them interesting and easily understandable.

(iii) **Recognition and capacity building of local institutions:**
Community-based institutions like VWSC, WATSAN, VP, WUG, etc. should be recognized and made responsible for the implementation of SSM projects for the sustenance of efforts. Water User Groups need to be formed for the governance of springs at the local level and funds for springshed development be released directly to these groups. These groups should be made responsible for the implementation of the SSM projects. Proper training should be imparted to the Gram Panchayats (including sub-committees) in order to build the capacity of the local communities, giving a special focus on women's involvement.

(iv) **Develop a trained cadre for para hydrogeologists:**
There is a need to develop a dedicated human resource for SSM at the community level. This can be done through the identification of village youth who could function as para-hydrogeologists after proper training. An incentive-based mechanism (IBM) should be put in place to encourage the above process. The trained para workers can help in demystifying the science of SSM. Capacity building (including guided mentoring) of para hydrogeologists can be integrated with Skill India Initiative.

(v) **SSM as part of the education curriculum:**
There is a need to build awareness about SSM from the school level itself. SSM can be considered an area of specialization in higher education.

(vi) **Convergence of institutions and cross learnings:**
Convergence of communities, gram panchayats, NGOs, and government departments are required to work together for SSM activities Regional-level consortiums or platforms (like the one in Uttarakhand) can encourage cross learnings and help in convergence among various stakeholders of SSM. There is a need to develop multi-stakeholder platforms at the state/district level.

(vii) **Integrate best management practices in capacity building:**
There is a need to integrate SSM with sewage management, water budgeting, demand management, livelihood activities, etc. A baseline survey of various aspects needs to be done for making proper impact assessment post interventions. Proper monitoring systems also need to be established for regular measurements of rainfall, discharge, and water quality. Sewage management can be done through convergence under Swatch Bharat Mission.

(viii) **Specialized and refresher courses:**
Specialized courses can be designed based on the specific needs of certain institutions. For example, urban springs are often neglected hence the gaps in the urban SSM can be filled by imparting specialized training to the concerned authorities. Feedback should be obtained regularly from the trained personnel once they apply the knowledge and skills acquired. This will help in identifying specific requirements based on which refresher courses, guided mentoring, and hand holding can be provided.

11.2.4 Capacity building materials

A note of caution regarding capacity building and capacity building materials needs to be highlighted at the onset. The diverse set of institutions required to undertake the restoration and revival of springs necessitates a demystified yet rich content and delivery of training and capacity building. If the content and delivery is of a kind that addresses researchers then the effort at creating knowledge, understanding and the skills to develop a robust programme on SSM might get defeated. Hence, a skill-based, demystified and continued capacity building programme needs to be thought through and designed. This programme also requires a sufficient degree of customisation based on the location-specific situation and conditions prevailing at the time of planning a SSM intervention.

A range of capacity-building materials is required which can be used as reference material by the various stakeholders involved in SSM. A lot of capacity-building materials already exist which need to be made available at one point, e.g. through the suggested national portal on SSM.

Development of training materials in local languages can help in bringing uniformity to the approach of SSM. It will also help in the effective and efficient dissemination of knowledge relating to SSM among various stakeholders. Short video films could be effective capacity-building tool. They can be made available in the local languages in order to make them understandable for the stakeholders at the local community and paraworker level. It is also important to keep these films short and interesting.

Annexure 1.1

List of attendees in one day brainstorming workshop on 'Development of Stranded Operating Procedure (SOP) for Springshed Management' at NIH, Roorkee on 15 May, 2023

S. No.	Name of the Officer/ invitee	Designation	Organization
1	Dr. Sudhir Kumar	Director	National Institute of Hydrology (NIH), Roorkee
2	Er. Sher Singh	Vice Chairman	Brahmputra Board, Guwahati, DoWR, RD&GR, Ministry of Jal Shakti, Govt. of India
3	Sh. D.S. Meena (IFS)	Additional Secretary (Forest)	Uttarakhand Forest Dept.
4	Er. S.K. Das	Chief Engineer	Department of Rural Development, Tripura
5	Dr. S.D. Khobragade	Scientist 'G'	National Institute of Hydrology (NIH), Roorkee
6	Dr. H.J. Shivaprasad	Professor	G B Pant University of Agriculture & Technology, Pantnagar, Uttarakhand
7	Dr. Sumit Sen	Associate Professor	Indian Institute of Technology, Roorkee
8	Dr. S.K. Barataryia	Scientist 'G' (Retd.)	Wadia Institute of Himalayan Geology (WIHG), Dehradun
9	Dr. Badrish Mehra	Excuitive Director	Central Himalayan Rural Action Group (CHIRAG), Uttarakhand
10	Dr. Debashish Sen	Director	People's Science Institute (PSI), Dehradun
11	Dr. M S Rao	Scientist 'F'	National Institute of Hydrology (NIH), Roorkee
12	Sh. R.K. Singh	Director (Watershed Management)	Dept. of Land Resources (DoLR), Ministry of Rural Development, Govt. of India
13	Dr. S.S. Rawat	Scientist 'F'	National Institute of Hydrology (NIH), Roorkee
14	Sh. Tapan Chakravarti	Scientist 'E'	Central Groundwater Board (CGWB), Faridabad
15	Dr. Prashant Rai	Regional Director	Central Groundwater Board (CGWB), Dehradun
16	Sh. Biplab Ray	Scientist 'E'	North Eastern Region , CGWB, Guwahati

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S. No.	Name of Officer/ invitee	Designation	Organization
17	Ajit Kumar Debbarma	Superintending Engineer	Planning & Design Unit, PWD (DWS), Agartala, Tripura
18	Er. S.K. Saha	Superintending Engineer	Irrigation Research Institute (IRI), Roorkee
19	Dr. D. Gnanasundar	Senior Joint Commissioner	National Hydrology Project
20	Dr. R.R. Purohit	Scientist 'D'	SUO, Agartala, CGWB
21	Dr. D.J. Khound	Scientist 'D'	North Eastern Region, CGWB, Guwahati
22	Dr. Som Dutt	Scientist 'D'	Wadia Institute of Himalayan Geology (WIHG), Dehradun
23	Dr. Santosh Murlidhar Pingale	Scientist 'D'	National Institute of Hydrology (NIH), Roorkee
35	Dr. Pramanada	Scientist 'D'	Forest Research Institute, Dehradun
24	Dr. Sandeep Bhatt	Assistant Professor	IIT, Roorkee
25	Dr. Vinod Kothari	Area Manger	Himmothan, Tata Trust, Uttarakhand
26	Sh. Nikhilesh Pant	Geologist	Himmothan, Tata Trust, Uttarakhand
28	Er. Vaibhav E. Gosavi	Scientist 'C'	G B Pant National Institute of Himalayan Environment, MoEF&CC, Govt. of India
29	Dr. D.S. Bisht	Scientist 'C'	NIH, Western Himalayan Regional Center (WHRC), Jammu
30	Dr. Nitesh Patidar	Scientist 'C'	National Institute of Hydrology (NIH), Roorkee
31	Dr. Abhilash R.	Scientist 'C'	NIH, Hard Rock Regional Center, Belagavi, Karanataka
32	Er. Manish Shankar Sant	Assistant Engineer	Irrigation Research Institute (IRI), Roorkee
33	Dr. Vikas Tomar	Scientist 'B'	Central Groundwater Board (CGWB), Dehradun

Annexure 1.2

List of Institutions Consulted

S. No.	Name of Agencies	Role in Springshed Management
1	GBPNIHE, Almora	Spring inventory and springshed mapping, hydrological modeling and promotion of springshed Management Programs under various schemes including NMHS
2	ACWADAM, Pune	Hydro-geological aspects, capacity building of state level stakeholders in Himalayan region, Western and Eastern ghats
3	CGWB	Capacity building programme in NE region and hydrogeology of the area
4	PSI, Dehradun	DTR preparation, spring water quality, capacity building of organizations, implementing springshed management programmes
5	CHIRAG, Almora	DTR preparation, implementation of springshed management, capacity building and field support
6	NIH, Roorkee	Spring inventory, Isotopic and geochemical investigations, hydrological modelling and impact assessment
7	PRASARI, West Bengal	DTR preparation, implementation of springshed Management, Capacity Building
8	NEIDA, Guwahati	DTR preparation, implementation of springshed management in North Eastern States
9	IIT, Roorkee	Hydrological modeling, instrumentation in springshed
10	GSI	Basic information in the form of geological/lithological maps of the area
11	NABARD and its partner organizations	Springshed based watershed development programmes
12	Watershed Management Directorate, Dehradun	Springshed management under watershed development and PMKSY programs
13	Land Resources Department, Kohima	Implementation of springshed management programs in Nagaland
14	Rural Development Departments of Himachal Pradesh, Sikkim and West Bengal	Implementation of springshed management programs
15	MBDA, Meghalaya	Implementation of springshed management programs under CLLMP and MEGLife Projects
16	Forest Departments of Himachal Pradesh, Manipur, and Uttarakhand	Implementation of springshed development of springs located in forest areas

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S. No.	Name of Agencies	Role in Springshed Management
17	Jal Shakti Vibhag of Arunachal Pradesh and Himachal Pradesh	Revival of drying springs feeding pipeline water supply schemes
18	NGOs including BAIF, HIMMOTHAN, CORD, MVS, and RTDC	Implementation of springshed development Programs
19	Arghyam, Bengaluru	Development of IEC materials on springshed management programs
20	ICIMOD, Nepal	Action Research on springshed management programs in the Hindu Kush Mountains

Annexure 3.1

FORMAT FOR LEVEL-I SURVEY

Rural-1/Urban-2 [ ]

I IDENTIFICATION PARTICULARS (Standard Codes to be used)

(a) State.. Code [| | |] (b) District... Code [| |]

For Rural
(a) Block/Tehsil.................................. Code [| | | | |] (d) Villages name......................... Code [| | | | |]

For Urban
(e) Town/Municipality.. Code [| | | | |] (f) Ward No. [| | | | |]

Serial no. of spring within village/town [| |]

Unique Identification Key for Spring *(If urban give code for town and ward)*

R/U	State		District			Tehsil/Town/Block						Village/Ward						Sl. No. within village/town		

Timestamp of Survey *[dd-mmm-yyyy hh:min]* [| | | |]

II SPRING DESCRIPTION

1. Locational Information
Latitude *(Degree Decimal)* [ ] Longitude *(Degree Decimal)* [ ] Altitude *(m, a.m.s.l.)* [ ]

2. Local Nomenclature of Spring...

3. Spring type: Free Flow-1, Seep-2 Code [ ]

4. Spring Nature: Perennial-1, Seasonal-2, Dried-3 Code [ ]

5. Whether this is a newly emerged spring *[within the last 10 years]:* Yes-1, No-2 Code [ ]

6. Does spring discharge muddy water in rainy season? Yes-1, No-2 Code [ ]

7. Cleanliness in and around the spring: Satisfactory-1, Unsatisfactory-2 Code [ ]

8. Spring ownership: Public-1, Private-2 Code [ ]

9. Whether there is any chamber/tank to collect the water? Yes-1, No-2 Code [ ]

10. Whether there is any pipe water supply from spring? Yes-1, No-2 Code [ ]

11. Capture three photographs for additional details
- (a) **Close up shot of spring** *(about 2 m from the spring outlet)*
- (b) **Wide angle shot of spring** *(about 10-20 m from the spring outlet)*
- (c) **Selfie with spring**

III GENERAL PHYSICAL CHARACTERISTICS OF THE SPRING

1. Whether spring discharge could be measured? Yes-1, No-2 Code [ ]

2. No. of spring outlets *[If the answer of III (1) is Code-1]* [ ]

Volume *(litres)* [ ] Duration *(min:sec)* [ ] Discharge *(litre per minute)* [ ]

3. Seasonal variability of the discharge across the year: High-1, Low-2 Code [ ]

4. Spring discharge trend in last 10 years:
Highly decreased-1, Slightly decreased-2, No change-3, Increased-4 Code [ ]

5. Colour of spring water: Colourless-1, Coloured-2 Code [ ]

6. Smell/odour of water: Agreeable-1, Non-agreeable-2 Code ☐

7. Taste of water: Objectionable-1, Unobjectionable-2 Code ☐

8. Temperature of spring water: Hot-1, Cold-2 Code ☐

IV OTHER INFORMATION

1. Dominant land use land cover in spring upstream:
Agriculture-1, Forest-2, Pasture-3, Shrubs-4, Settlement-5 Code ☐

2. Land use land cover in and around spring location:
Agriculture-1, Forest-2, Pasture-3, Shrubs-4, Settlement-5 Code ☐

3. Resource threat: Yes-1, No-2 Code ☐

i.e., Code-1, fill the following details,

(a) Degree of threat: Low-1, Moderate-2, High-3 Code ☐

(b) Major stressor responsible for threat *(up to three codes, in the order of preference):*
Drought-1, Forest Fire-2, Scouring/Gully Erosion-3, Landslide/Subsidence-4, Code ☐
Earthquake-5, Avalanche-6, Urbanisation-7, Deforestation-8 , Pollutant load-9, Code ☐
Introduction of non-native plants-10, Animal grazing-11, Min ing-12, Other-13 Code ☐

4. Usage of spring water *(up to three codes, in the order of preference):* Code ☐
Drinking/Cooking-1, Washing/Sanitation, Cattles/Livestock-3, Code ☐
Irrigation-4, Indutrial-5, Other-6 Code ☐

5. Dependent type: Residents-1, Non-residents-2, Wild animals-3, Not applicable-4 Code ☐

If the answer of IV (5) is Code-1, fill the following details,

(a) Number of dependent villages: ☐☐
(b) Name of dependent villages:
(c) Number of dependent households: ☐☐☐☐
(d) Number of dependent people: ☐☐☐☐☐

6. Dependency level: Low-1, Moderate-2, High-3 Code ☐

7. Other available source of water *(select multiple options, if applicable):*
Other spring-1, Piped supply-2, Hand pump-3, Dugwell-4, Pond-5, None-6, Other-7 Code ☐

8. Whether the spring has undergone any springshed/watershed management program? Code ☐
Yes-1, No-2, Not known-3

Remarks, if any:
Checked by:
Name:
Designation of Supervisory Officer:
Mobile No.:

Signature of Enumerator:
Name:
Designation of Enumerator:
Mobile No.:

Annexure 3.2

FORMAT FOR LEVEL-II SURVEY

Rural-1/Urban-2 [ ]

I IDENTIFICATION PARTICULARS (Standard Codes to be used)

(a) State.. Code [ ] (b) District.. Code [ ]

For Rural
(a) Block/Tehsil.................................... Code [ ] (d) Villages name......................... Code [ ]

For Urban
(e) Town/Municipality... Code [ ] (f) Ward No. [ ]

Serial no. of spring within village/town [ ]

Unique Identification Key for Spring *(If urban give code for town and ward)*

R/U	State	District	Tehsil/Town/Block	Village/Ward	Sl. No. within village/town

Timestamp of Survey *[dd-mmm-yyyy hh:min]* [ ]

II SPRING DESCRIPTION

1. Locational Information
Latitude *(Degree Decimal)* [ ] Longitude *(Degree Decimal)* [ ] Altitude *(m, a.m.s.l.)* [ ]

2. Local Nomenclature of Spring..

3. Spring type: Free Flow-1, Seep-2 Code [ ]

4. Spring Nature: Perennial-1, Seasonal-2, Dried-3 Code [ ]

5. Whether this is a newly emerged spring *[within the last 10 years]*: Yes-1, No-2 Code [ ]

6. Does spring discharge muddy water in rainy season?: Yes-1, No-2 Code [ ]

7. Cleanliness in and around the spring: Satisfactory-1, Unsatisfactory-2 Code [ ]

8. Spring ownership: Public-1, Private-2 Code [ ]

9. Whether there is any chamber/tank to collect the water? Yes-1, No-2 Code [ ]

10. Whether there is any pipe water supply from spring? Yes-1, No-2 Code [ ]

11. Capture three photographs for additional details
(i) **Close up shot of spring** *(about 2 m from the spring outlet)*
(ii) **Wide angle shot of spring** *(about 10-20 m from the spring outlet)*
(iii) **Selfie with spring**

12. Any permanent structure on spring? Yes-1, No-2 Code [ ]

13. Hydrogeological Information
(i) **Spring Typology:** Depression-1, Contact-2, Fracture/Fault-3, Karast-4, Thermal-5 Code [ ]
(ii) **Rock type:** Phyllite-1, Schist-2, Shale-3, Sandstone-4, Limestone-5, Granite-6, Gneiss-7, Basalt-8, Quartzite-9, any ot her type-10 (mention the same) Code [ ]
(iii) **Aquifer type:** Confined-1, Unconfined-2, Karst-3 Code [ ]

14. Topographical feature: Hill top-1, Middle of the hill-2, valley/bottom of the hill-3 Code [ ]

15. Settlement near the spring: Yes-1, No-2 Code [ ]

17. Accessibility to spring: Easy-1, Moderate-2, Difficult-3 Code [ ]

III GENERAL PHYSICAL CHARACTERISTICS OF THE SPRING

1. Whether spring discharge could be measured? Yes-1, No-2 Code [ ]

2. No. of spring outlets *[If the answer of III (1) is Code-1]* Code [ ]

Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	
Volume *(litres)*		Duration *(min:sec)*		Discharge *(litre per minute)*	

3. Seasonal variability of the discharge across the year: High-1, Low-2 Code [ ]

4. Peak months of discharge *(select multiple months up to three, if applicable):*

January-1, Feburary-2, March-3, April-4, Code [ ]
May-5, June-6, July-7, August-8, Code [ ]
September-9, October-10, November-11, December-12 Code [ ]

5. Lean months of discharge *(select multiple months up to three, if applicable):*

January-1, Feburary-2, March-3, April-4, Code [ ]
May-5, June-6, July-7, August-8, Code [ ]
September-9, October-10, November-11, December-12 Code [ ]

6. Spring discharge trend in last 10 years:
Highly decreased-1, Slightly decreased-2, No change-3, Increased-4 Code [ ]

7. Colour of spring water: Clean-1, Yellowish-2, Reddish-3, Brownish-3, Greyish-4, Greenish-5, Other-6 Code [ ]

8. Smell/odour of water: Agreeable-1, Non-agreeable-2 Code [ ]

9. Taste of water: Objectionable -1, Unobjectionable-2 Code [ ]

10. Electrical conductivity of water (µS/cm)

11. pH of water *(in decimal)*

12. Temperature of spring water *(°C)*

13. Dissolved Oxygen *(mg/l)* .

IV SPRING WATER SAMPLE COLLECTION FOR LAB ANALYSIS

1. 100 ml sample for major Ions: Yes-1, No-2 Code [ ]

2. 60 ml sample for Carbonates and Bi-carbonates: Yes-1, No-2 Code [ ]

3. 60 ml sample for trace elements: Yes-1, No-2 Code [ ]

4. 15 ml sample for stable isotope of Hydrogen and Oxygen: Yes-1, No-2 Code [ ]

5. 500 ml sample for Tritium: Yes-1, No-2 Code [ ]

V OTHER INFORMATION

1. Dominant land use land cover in spring upstream:
Agriculture-1, Forest-2, Pasture-3, Shrubs-4, Settlement-5 Code [ ]

2. Land use land cover in and around spring location:
Agriculture-1, Forest-2, Pasture-3, Shrubs-4, Settlement-5 Code [ ]

3. Resource threat: Yes-1, No-2 Code [ ]

i.e., Code-1, fill the following details,

(a) Degree of threat: Low-1, Moderate-2, High-3 Code [ ]

(b) Major stressor responsible for threat: Natural-1, Anthropogenic-2, Both-3 Code [ ]

(c) **Based on the option selected in IV (3) (b) select the appropriate options:**

(c1) Natural stressor *(up to three codes in order of preference):*
Drought-1, Forest Fire-2, Scouring/Gully Erosion-3
Landslide/Subsidence-4, Earthquake-5, Avalanche-6, Other-7
Code
Code
Code

(c2) Anthropogenic stressor *(up to three codes in order of preference):*
Urbanisation-1, Deforestation-2, Pollutant load -3
Introduction of non-native plants-4, Animal grazing-5, Mining-6, Other-7
Code
Code
Code

(c3) Both Natural and Anthropogenic stressor *(up to three codes in order of preference):*
Drought-1, Forest Fire-2, Scouring/Gully Erosion-3, Landslide/Subsidence-4,
Earthquake-5, Avalanche-6, Urbanisation-7, Deforestation-8 , Pollutant load-9,
Introduction of non-native plants-10, Animal grazing-11, Mining-12, Other-13
Code
Code
Code

4. Usage of spring water *(up to three codes in order of preference):*
Drinking/Cooking-1, Washing/Sanitation, Cattles/Livestock-3,
Irrigation-4, Indutrial-5, Other-6
Code
Code
Code

5. Dependent type: Residents-1, Non-residents-2, Wild animals-3 Code

If the answer of IV (5) is Code-1, fill the following details,

(a) Number of dependent villages:
(b) Name of dependent villages:
(c) Number of dependent households:
(d) Number of dependent population:
(e) Number of dependent livestock:

6. Dependency level: Low-1, Moderate-2, High-3 Code

7. Other available source of water *(select multiple options, if applicable):*
Other spring-1, Piped supply-2, Hand pump-3, Dugwell-4, Pond-5, None-6, Other-7 Code

8. Whether the spring has undergone any springshed management program? Yes-1, No-2, Not known-3 Code

i.e., Code-1, provide detail of the impact of springshed management program as follows,

(a) Change in spring discharge: Increased-1, Decreased-2, No change-3 Code
(b) Longevity of spring discharge: Increased-1, Decreased-2, No change-3 Code
(c) Spring water quality: Improved-1, Degraded-2, No change-3 Code

9. Whether the recharge area of spring has been demarcated? Yes-1, No-2 Code

10. Whether the discharge of spring is being measured regularly? Yes-1, No-2 Code

11. Whether local residents feel the need of springshed management program? Yes-1, No-2 Code

12. Community Perception:
(i) Concerns
(ii) Any feedback they provide

13. Erosion Control Measures near the spring: Yes-1, No-2 Code

14. Community Initiatives taken to spring conservation or management: Yes-1, No-2 Code

Remarks, if any:
Checked by:
Name:
Designation of Supervisory Officer:
Mobile No.:

Signature of Enumerator:
Name:
Designation of Enumerator:
Mobile No.:

Annexure 11.1

Capacity Building Needs of Functionaries involved in springshed management

Step	Particulars	Capacity Building Gaps/Needs			
		Community and GP Level	Para Workers	Extension Agencies: GO/NGOs	Policy/Decision Makers
1	Comprehensive Mapping of Springs and Springsheds	Convergence with GPDPs, Importance of water quality	Recording Oral history; Water Resources Assessment; Water Budgeting	Mapping Tools; Standard Template for Spring Inventory; Water Quality	Springsheds as ecosystems; Concept of Spring Sanctuaries
2	Setting up a Data Monitoring System	Community based monitoring tools	Data Collection and Interpretation	Spring Hydrology Modeling; Long term monitoring	Convergence with Res. Inst.
3	Understanding Social and Governance Systems of Springs	Convergence with VWSC/ WATSAN/ MMD	Community Mobilization	Role of Community Based Institutions	Participatory Spring Governance
4	Hydrogeological Mapping, development of conceptual layout and identification of recharge area	Demystifying hydrogeology	Hydro-geological aspects of springshed and aquifer	Hydro-geological aspects of springshed and aquifer	Looking beyond administrative boundaries
5	Developing springshed management and governance protocols	Water sharing, sanitation practices, biomass sharing, etc.	Conflict Resolution	Integrating with NR mgt., septic mgt. and demand mgt.	CPR Mgt., Convergence of govt. depts. and schemes
6	Measuring the impacts of spring revival activities	Participatory Assessment	Base line surveys	Means of Verification; Cost benefit analysis	Result Framework

Annexure 11.2(A)

Training Modules for Community and GP Level

Training Module – I

THEORY:

- Significance of groundwater
- Introduction to the concept of springs
- Importance of community participation
- Formation of Water User Groups and convergence with VWSC/WATSAN/ MMD
- Protocols for Water User Groups including social fencing, sharing of water, contributions
- Water sharing, sanitation practices, and biomass sharing
- Conducting PRA activities
- Importance of water quality and discharge measurement

FIELDWORK:

- Community-based water quality and discharge measurement
- Exposure visits

Training Module – II

THEORY:

- Revision of the first training
- Relevance of trenches and other structures in the recharge area
- Community based monitoring and decision making
- Convergence with different agencies and government departments
- Participatory impact assessment

FIELDWORK:

- Construction of trenches and its protocols
- Recharge area protection activities
- Maintenance of the recharge area

Annexure 11.2(B)

Training Modules for Para Hydrogeologists

Training Module – I

THEORY:

- Significance of groundwater
- Introduction of Springshed
- Springs typology and hydro-geological aspects
- Community mobilization
- Introduction of PRA exercises and record oral history
- Water resource assessment and water budgeting
- Importance of water quality measurement
- Spring discharge and rainfall data interpretation
- Relation between discharge and rainfall measurement
- Basic as well as detailed water quality parameters
- Format of baseline survey
- Data analysis and interpretation

FIELDWORK:

- Transit walk, identification of springs and rocks, geological mapping
- PRA exercises with the community
- Analysis of the PRA results
- Installation of rain gauge
- Discharge and Rainfall measurement
- In-situ parameters of water quality testing
- Water demand and supply gap estimate
- Data analysis and interpretation

Training Module – II

THEORY:

- Revision of the first training
- Various engineering and vegetative measures for different land uses and slopes
- Design and estimates of measures
- Maintenance of records and documentation related to the payment for the recharge activities
- Carrying out convergence activities and writing proposals for the same

- Formation of Water User Groups
- Protocols for Water User Groups including social fencing, sharing of water, contributions
- Conflict Resolution
- Conducting awareness programs for communities
- Protection of recharge area

FIELDWORK:

- Identification of recharge area
- Contour mapping, use of A-Frame, and slope measurement
- Layout of trenches
- Sensitization of the community regarding recharge activities and convincing landowners to carry out recharge activities on their land
- Supervision and monitoring of recharge activities

Annexure 11.2(C)

Training Modules for Extension Agencies

Training Module – I

THEORY:

- Groundwater and its significance
- Introduction to springs
- Introduction to geology and hydrogeological properties of the rocks
- Introduction to Springshed Management
- Spring discharge measurement
- Groundwater quality: An introduction
- In-situ water quality testing
- Springshed planning: Water demand, supply and gap estimates
- Introduction to the use of instruments like GPS, Brunton
- Community mobilization (Sandesh Yatra)
- Participatory mapping tools like social and resource mapping
- Spring Inventory

FIELDWORK:

- Transect walk, Social and Resource Mapping
- Water budgeting
- Identification of springs and rocks
- Geological mapping
- Discharge measurements and water quality testing

Training Module – II

THEORY:

- Revision of the first training
- Identification of recharge area
- Springs regeneration methods
- Engineering survey: contour mapping: use of A-Frame, slope measurement
- Engineering and Vegetative measures
- Integration with natural resource management, demand management, and septic management

FIELDWORK:

- Slope measurement
- Contour mapping
- Layout of SCTs

Training Module – III

THEORY:

- Revision of the second training
- Community Based Institutions
- Formation of Spring Water User Group
- Protocols for WUGs including social fencing, sharing of water, and contributions.
- Monitoring Systems: Rainfall, Discharge & Quality
- Data Analysis and Interpretation
- Cost Benefit Analysis

FIELDWORK:

- Formation of WUG
- Installation of rain gauges
- Data Collation, Analysis, and Interpretation

Annexure 11.2(D)

Training Modules for Policy/Decision Makers

Training Module

THEORY:

- Groundwater and its significance
- Introduction to springs and springsheds ecosystem
- Concept of Spring Sanctuaries
- 6 Step Methodology of Springshed Management
- Introduction to hydrogeology of springs
- Introduction to the concept of springshed management vs watershed management
- Participatory mapping of springs
- Spring Treatment Measures
- Spring governance including protocols for WUGs
- Result Framework: Baseline Survey and Impact Assessment
- Research areas
- Convergence

FIELDWORK:

- Field visit of successful springshed management sites
- Interactions with WUGs
- Monitoring system (Rainfall, Discharge and Water Quality)

References

Alfaro, C., & Wallace, M. (1994). Origin and classification of springs and historical review with current applications. *Environmental Geology*, *24*, 112–124.

Board, C. P. C. (2007). Guidelines for water quality monitoring.

Chadha, D. (1999). A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeology journal*, *7*, 431–439.

Chen, D., Wei, W., & Chen, L. (2020). How can terracing impact on soil moisture variation in china? a meta-analysis. *Agricultural Water Management*, *227*, 105849.

Chow, V. T. (1964). Handbook of applied hydrology: a compendium of water-resources technology. In *Handbook of applied hydrology: a compendium of water-resources technology*, (pp. 1525–1525).

Clarke, F. (1924). Mineral wells and springs. *The data of geochemistry. US Geological Survey, Reston, VA*, (pp. 181–217).

Critchley, W., Siegert, K., Chapman, C., & Finket, M. (2013). *Water harvesting: A manual for the design and construction of water harvesting schemes for plant production*. Scientific Publishers.

Dar, T., Rai, N., & Kumar, S. (2022). Distinguishing mountain front and mountain block recharge in an intermontane basin of the himalayan region. *Groundwater*, *60*(4), 488–495.

IMSD (1995). Integrated mission for sustainable development technical guidelines. *National Remote Sensing Agency, Department of Space, Govt. of India*.

Institute, F. R. (2018). Road map for ecological restoration works in coal mines of ncl, singrauli, m.p.

Jambay, & Uden, K. (2022). Springshed: identifying recharge areas of drying springs and lakes with water quality in southwestern bhutan. *Tarayana Foundation*.

Kalbus, E., Reinstorf, F., & Schirmer, M. (2006). Measuring methods for groundwater, surface water and their interactions: a review. *Hydrology and Earth System Sciences Discussions*, *3*(4), 1809–1850.

Karanjac, J., & Altug, A. (1980). Karstic spring recession hydrograph and water temperature analysis: Oymapinar dam project, turkey. *Journal of Hydrology*, *45*(3-4), 203–217.

Kresic, N., & Bonacci, O. (2010). Spring discharge hydrograph. In *Groundwater hydrology of springs*, (pp. 129–163). Elsevier.

Kresic, N., & Stevanovic, Z. (2009). *Groundwater hydrology of springs: engineering, theory, management and sustainability*. Butterworth-heinemann.

Kulkarni, S., Bhagat, N., Fu, M., Kedigehalli, V., Kellogg, C., Mittal, S., Patel, J. M., Ramasamy, K., & Taneja, S. (2015). Twitter heron: Stream processing at scale. In *Proceedings of the 2015 ACM SIGMOD international conference on Management of data*, (pp. 239–250).

Meinzer, O. E. (1923). Outline of ground-water hydrology, with definitions. Tech. rep., US Govt. Print. Off.,.

Mohamed, A. R., Hamid, N., & Elamin, A. M. (2010). Rainwater harvesting techniques for soil moisture conservation on the upper terraces of the blue nile-sennar state (sudan).

Negi, G., & Dhyani, P. E. (2012). *Glimpses of Forestry Research in the Indian Himalayan Region*. Almora: G.B. Pant Institute of Himalayan Environment & Development.

NITI Aayog (2018). Report of working group i: Inventory and revival of springs in the himalayas for water security.
URL `https://niti.gov.in/writereaddata/files/document_publication/doc1.pdf`

Pacheco, F. A., & Alencoão, A. M. (2006). Role of fractures in weathering of solid rocks: narrowing the gap between laboratory and field weathering rates. *Journal of Hydrology*, ***316***(1-4), 248–265.

Pérez, E. S. (1996). Springs in spain: classification according to their flows and lithologies and their hydraulic contributions. *Groundwater*, ***34***(6), 1033–1041.

Pitts, M. W., & Alfaro, C. (2001). Geologic/hydrogeologic setting and classification of springs. In *Springs and Bottled Waters of the World: Ancient History, Source, Occurence, Quality and Use*, (pp. 33–71). Springer.

Rawat, S., Jose, P., Rai, S., & Hakhoo, N. (2018). Spring sanctuary development sustaining water security in the himalayan region in changing climate. In *Proc. of International Conference on Water Environment and Climate Change Knowledge Sharing and Partnership*, (pp. 151–159).

Shanker, R., Guha, S., Seth, N., Muthuraman, K., Pitale, U., Jangi, B., Prakash, G., Bandopadhyay, A., & Sinha, R. (1991). *Geothermal Atlas of India*. Special Publication No. 19. Geological Survey of India.

Shrestha, R. B., Desai, J., Mukherji, A., Dhakal, M., Kulkarni, H., Mahamuni, K., Bhuchar, S., & Bajracharya, S. (2018). *Protocol for reviving springs in the Hindu Kush Himalayas: A practitioner's manual*. International Centre for Integrated Mountain Development (ICIMOD).

Singh, N., & Ranade, A. (2010). The wet and dry spells across india during 1951–2007. *Journal of Hydrometeorology*, *11*(1), 26–45.

Singh, V. P. (1988). *Hydrologic Systems–Watershed Modeling Vol. 2*. New Jersey: Prentice Hall.

Sophocleous, M. (2002). Interactions between groundwater and surface water: the state of the science. *Hydrogeology journal*, *10*, 52–67.

Tambe, S., Kharel, G., Arrawatia, M., Kulkarni, H., Mahamuni, K., & Ganeriwala, A. K. (2012). Reviving dying springs: climate change adaptation experiments from the sikkim himalaya. *Mountain Research and Development*, *32*(1), 62–72.

"There is a need to expedite efforts for the revival of springshed in mountainous areas of country."

-Hon'ble Prime Minister of India
1st All India Annual States' Ministers Conference
on "Water Vision@2047", January, 2023

This document is an Initiative of the Steering Committee for *Springshed Mapping of IHR Including Mountainous Regions of the Country and Springshed Based Watershed Management Plan* constituted by DoWR, RD & GR, Ministry of Jal Shakti, Govt. of India.