

**WEB GIS BASED SPRING INVENTORY FOR VULNERABILITY ASSESSMENT
AND HYDRO-GEOLOGICAL INVESTIGATION OF SELECTED SPRINGS FOR
SUSTAINING LOCAL WATER DEMAND IN RAVI CATCHMENT OF
HIMACHAL PRADESH (NIH-21_2017_31)**



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PREFACE

Springs are the lifeline of people residing in the mountainous regions of our country. Notably, approximately 200 million Indians, constituting around 15% of the country's population, depend on springs for their daily water needs. These springs are widely distributed across the mountainous areas, nourishing countless small and large streams that support the growth of civilization, agriculture, industry and economic activities in our nation

Recognizing the importance of springs for water as well as ecological security, now the Government has placed these traditional water resources as highest priority for sustaining the sources in the state. However, it has been observed that non-availability of basic hydro-meteorological and physico-chemical data on these traditional water resources are the major causes due to which springs could not receive due importance in the policy and planning. NITI Aayog, in its working group report on “Inventory and Revival of springs for water Security in the Himalayas”, has stressed upon the need of a Web-GIS platform where all implementing agencies can geotag their springs. Therefore, the development of a scientific database, along with monitoring of local springs becomes imperative for managing water requirements for various developmental and household needs. The Purpose Driven Study (PDS) entitled “Web GIS-based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh” carried-out by National Institute of Hydrology, Roorkee with the support of *Jal Shakti Vibhag*, Himachal Pradesh for the development of detailed basic database of the springs of Ravi River catchment is an utmost important step towards the development of holistic understanding of springs and their groundwater systems in the catchment. It aims to address the key issues related to conservation and sustainable management of the natural resources in the Ravi River catchment, ultimately protecting and reviving the local springs to ensure long-term water and ecological security for the state. To provide detailed information about the Ravi River catchment of Himachal Pradesh, web-GIS portal named ISHVAR (**I**nformation **S**ystem of **H**imalayan **S**prings for **V**ulnerability **A**ssessment and **R**ejuvenation) has been developed by the Institute under this PDS. Such web-GIS based spring inventory holds immense importance in safeguarding springs and their springsheds during various developmental activities and to formulate effective springshed development programs. Further, the available information will be helpful for the state and central government agencies in prioritizing their springshed programs in both space and time.

I appreciate the efforts of the entire team of the PDS in bringing out such a detailed and informative report, spring atlas under the PDS. Their dedication and hard work have resulted in a valuable resource that will significantly contribute to the conservation and sustainable management of springs in our country. The work carried-out in the PDS has been appreciated at different platforms and format and mechanism developed in the PDS is already implemented in the form of initiation of “First Spring Census” of the country by DoWR, RD&GR, Ministry of Jal Shakti, Govt. of India.

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Abstract Innumerable springs exist throughout the length and breadth of Indian Himalayan Region serving as major sources of drinking, domestic and irrigation needs while also, playing a major role in maintaining various ecosystems of the region. The water demand in the rural areas is much higher than that of urban areas as a majority of the population of the Himachal Pradesh, a Himalayan state of India, lives in the rural areas. Furthermore, there is an imbalance between the supply and consumption of water, particularly by the poor and weaker section of society, where the traditional sources of water (normally springs) play a significant role. Keeping the importance of traditional water resources in sustaining the water demand of the mountainous states in view, planning commission (now NITI Aayog) of government of India gave emphasis on creation of a traditional water resources cell in the state for development and proper care of traditional water resources in view of changing climate and increasing anthropogenic activities. NITI Aayog has also given stress on creation of a web-enabled database for mapping of springs across the Himalayas in its Working Group-I report titled “Inventory and Revival of Springs in the Himalayas for	

Water Security”. In this regard, a Purpose Driven Study (PDS) entitled “Web GIS based spring inventory for vulnerability assessment and hydro-geological investigation of selected springs for sustaining local water demand in Ravi catchment of Himachal Pradesh” was approved for Western Himalayan Regional Center, Jammu (Regional Center of NIH, Roorkee) in August, 2017 under the aegis of National Hydrology Project (NHP). Himachal Pradesh Jal Shakti Vibhag is the implementing department from the state in this PDS.

Considering various parameters crucial for springshed management, a Spring Data Collection (SDC) format was developed for survey of present status of the springs in Ravi River catchment of Himachal Pradesh. Initially springs were geotagged by handheld GPS and information were filled in a paper form. However, it was realized that digitization of paper-based SDC form is a cumbersome process and having high possibilities of manual errors. Therefore, SDC form was transformed and customized as per user convenience in a mobile app using KoBo toolbox for the survey work of the remaining part of the catchment. Mobile app has capability to transfer the data to the admin instantaneously, which omitted the necessity to go to the field for collecting the filled SDC from the surveyor. Furthermore, it helped us at large extent to conduct survey during COVID-19 pandemic when interstates movements were restricted. A spring inventory of 981 springs is created after carrying out a detailed survey in 8 tehsils of the Chamba district (one of the aspirational districts of Himachal Pradesh declared by NITI Aayog) falling under Ravi River catchment. Spring database offers an inventory based on 30+ parameters comprising general information (*village, gram panchayat, tehsil, district, latitude, longitude, elevation, Spring type, Nature, Purpose of use, discharge, people perception about discharge, lean and peak month of discharge, name and telephone of information provider, name and mobile number of gram pradhan*); demographic information (*dependent villages/household/population/ livestock*), level of dependency, land ownership and land use in the vicinity of spring and upstream side; and water quality information (*taste colour, odour, pH, EC, TDS, Alkalinity, Iron, Sodium, Calcium, Potassium, Calcium, Magnesium, Carbonate, bicarbonate, Chloride, Fluoride, Nitrate, Sulphate*) of spring's water. Based on the collected information a spring atlas comprising the various characteristics of 981 springs have been developed (<http://117.252.14.250:8080/jspui/handle/123456789/7443>). Through hydro-chemical analysis, the study elucidates the composition and quality of spring water, identifying potential sources of contamination and assessing overall water quality in the catchment. Furthermore, spatial maps developed for various water quality parameters using springs point data are very useful for the implementing agencies to find out the suitable sources of

water in the area. The study also investigates seasonal variations in isotopic signatures of precipitation, providing insights into recharge mechanisms and hydrological processes. Understanding these dynamics is essential for predicting water availability and managing groundwater resources effectively.

The inventory is hosted in a GIS enabled web portal named, **Information System of Himalayan springs for Vulnerability Assessment and Rejuvenation (ISHVAR)**. Web-GIS portal was developed using *GeoServer, HTML, and JavaScript* to display the geospatial information. The developed web portal has capabilities to create, store, access and represent the geo-spatial data to enables the effective communication between different stakeholders, citizens and decision makers. The developed Web-GIS portal has been appreciated at various platforms and an event on the theme titled “Enabling policymakers in facilitating water security and source sustainability through creation of web GIS enabled inventory of Himalayan Spring” based on this portal was organized in United Nation (UN) workshop COP28 held at Dubai during 30 November 2023 to 12 December, 2023.

Vulnerability of the surveyed springs have been estimated based on the factors related to the springs, including (a) spring discharge magnitude, (b) year-round availability of spring water, (c) population dependent on the spring, (d) level of dependence on the spring, (e) availability of alternative water sources, (f) variability of spring water flow, (g) measurement of Total Dissolved Solids, and (h) pH level. All surveyed springs were categorized in three different categories of vulnerability i.e., ‘highly vulnerable’, ‘moderately vulnerable’ and ‘least vulnerable’. Out of 981 Springs, 231 Springs were found to be ‘highly vulnerable’ while rest 750 were ‘moderately vulnerable’, none of the spring was found to be ‘least vulnerable’. By developing a vulnerability index and zonation map, the study identifies the springs and areas as well which are most susceptible to degradation of water resource in the catchment. This methodology allows for a systematic evaluation of springs, enabling the identification of high-priority springs and informing decision-making processes related to resource allocation and management in the Ravi River catchment.

Detailed hydrogeological investigations of six vulnerable springs have been conducted to understand the hydrological behavior of springs in different parts of the catchment. Study investigates seasonal variations in isotopic signatures of precipitation, providing insights into recharge mechanisms and hydrological processes. Understanding these dynamics is essential for predicting water availability and managing groundwater resources effectively. Possible recharge area of the springs has been identified by tracing the groundwater flow path of the spring through hydrogeological investigations in the vicinity of springs. Such

field mapping is necessary to understand the various characteristic (dip, strike, geological cross-section, porosity, transmissivity, etc.) of local rocks and its structure analysis (fractures, faults, etc.) to understand the groundwater flow movement in the local area.

The training of field functionaries of the line departments and data collector under the project was conducted to ensure the accurate data collection under the project and other schemes of the state government. A one-day stakeholders' workshop on "*Web-GIS-based Spring Information System*" was organized in virtual mode to share the functionality of the portal and also obtained their feedbacks for making portal more interactive and informative. Information regarding the importance of springs in sustaining the water demand, supporting ecosystem and regional biodiversity and the current status of springs in the Ravi River basin were shared with school students and villagers through various forums. Finally, the project outcome was shared with the stakeholders through a one-day Stakeholders Sensitization workshop on 'Status of Traditional Water Resources (Springs) of Ravi River Catchment' organized at Government Degree College, Chamba, Himachal Pradesh. All activities taken under this PDS is summarized in the form of a small video (https://drive.google.com/file/d/1VlSUtKfjDEzRA8cy67OAIWBEVEN8Qg-O/view?usp=drive_link).

Keywords: Himalayan springs, Hydrochemistry, Isotope, Ravi River catchment, Web-GIS spring inventory,

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1. INTRODUCTION

1.1. General

Springs are the main and dependable source of drinking water of more than 40 million inhabitants of the Himalayan region; for this reason, villages are clustered around natural water springs in the Himalayan region. Springs are naturally occurring formations and hence a common water source for local community. In addition to this, these springs are the life of several rivers and there is hardly any river which is not fed by a spring. Hence these springs are the lifeline of several micro-habitats in the river systems. However, increasing population and unplanned development have adversely affected the recharge processes and resulted in depletion of this prime water resource in the entire Himalayan region. Furthermore, depletion of these springs is also exacerbated by rising air temperatures, marked decline in winter rainfall and in general, the erratic and torrential rainfall that has replaced the monsoon drizzles of yore. It has been estimated that less than 15% of the rainwater is able to percolate down to recharge the springs, while the remaining flows down as runoff, often causing floods. It is believed that nearly half of the perennial springs in IHR have already dried up or have become seasonal and tens of thousands of villages are currently facing acute water shortage for drinking and other domestic purposes (NITI Aayog, 2018). In such a circumstance, women and children are forced to travel longer distances to fetch a head-load of water, which increases their drudgery, while sacrificing their valuable time to carry-out other works essential for livelihood. Reduced access to water in turn impacts health, hygiene, sanitation and limits the livelihood options as well (Tambe et al., 2012).

In the mountainous areas of Himachal Pradesh, most villages are located at high altitudes, mainly on ridges as scattered hamlets. Thus, people of these villages are at a great disadvantage for accessing water, as most of the streams originating in the Himalaya flow in the deep valleys, making them inaccessible. In such a situation, natural water springs or traditional water resources (locally known as *Baori*, *khatri*, *Naun*, *panihar*, *Chharedu* in the State) are the only dependable sources of water. It is believed that nearly half of the perennial springs throughout the mountainous areas has already dried up or has become seasonal, forcing villagers to move wherever water moves. Both natural and anthropogenic

factors are believed to be responsible for depletion of quantity (spring flow) and deterioration of quality of spring water in the region.

Furthermore, the demand for the water in the rural areas is much higher than in urban areas as a majority of the population of the Himachal Pradesh lives in the rural areas. Nevertheless, there is an imbalance between the supply and consumption of water, particularly by the poor and weaker section of society, the traditional sources (normally springs) of water play a significant role. There are 10512 traditional sources of water in the Himachal Pradesh for drinking water in rural habitats (Survey of status of drinking water in rural habitats, 1991-93). Chamba district comprises about 2598 traditional water resources which is maximum among all the districts of the state. According to Himachal Pradesh Human Resource Development Report (2002), water demand for the population of Chamba district will increase from 36.53 mld (2001) to 58.04 mld (2021). About 85% of this total water demand is from the rural areas that are largely dependent on traditional water resources. HP State Council for Science, Technology and Environment (HIMCOSTE) has done a survey in 169 *Panchayats* of seven districts in the state of Himachal Pradesh on traditional water sources, which clearly showed that there were only 30% sources in good working condition and recharging properly throughout the year, while 70% sources were not in proper working condition and going to dry up in near future (Fig. 1.1). In Chamba district, less than 1% sources were found working well, while more than 99% were in poor condition. It is worth noting that the entire Chamba district is part of Ravi river catchment. Keeping in view of the importance of traditional water resources in sustaining the water demand of the state, planning commission of government of India gave emphasis on creation of a traditional water resources cell in the state for development and proper care of traditional water resources in view of changing climate and increasing anthropogenic activities.

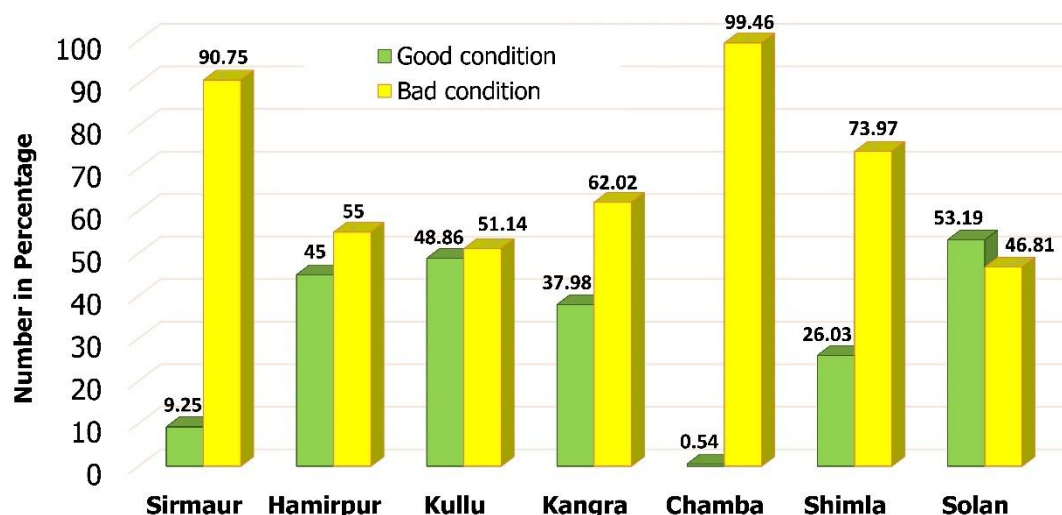


Fig. 1.1. Status of traditional water sources in Himachal Pradesh. *Source: Report of H P State Council for Science Technology and Environment on 'Directory of water resources in Himachal Pradesh'*

Keeping in view of the importance of traditional water resources in sustaining the water demand of the State, the Planning Commission (now NITI Aayog), Government of India gave emphasis on creation of a traditional water resources cell in Himachal Pradesh for development and proper care of traditional water resources in view of changing climate and increasing anthropogenic activities.

Therefore, it is the need of the hour to map these traditional water resources for their protection and proper management to maintain both quality and quantity in time and space. With this motive, a Purpose Driven Study (PDS) entitled “Web GIS based spring inventory for vulnerability assessment and hydro-geological investigation of selected springs for sustaining local water demand in Ravi catchment of Himachal Pradesh” has been initiated by Western Himalayan Regional Centre (WHRC), Jammu, one of the six regional centers of National Institute of Hydrology (NIH), Roorkee in August, 2017 under the aegis of National Hydrology Project (NHP), Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Govt. of India. Himachal Pradesh Jal Shakti Vibhag (formerly known as Irrigation & Public Health Department) is the implementing department from the state in this Purpose Driven Study (PDS).

1.2. Objectives of the Study

The broad objective of initiating this spring-based project is setting up of a web-database which will not only facilitate data on springs to government departments, NGOs, CDOs and individuals for effective management of their water related programmes, but also the baseline data for research institutes for focusing their research projects to develop better understanding of hydro-geology of Himalayan springs. Moreover, this database will help to take stock of the magnitude of the problem (drying of springs, deteriorating water quality of springs) in space and time. Furthermore, development of protocol/adaptive measures for sustaining the vulnerable springs in Ravi River catchment in particular and in Indian Himalayan Region (IHR) in general is also another objective of the study. Another objective of the project, viz. the creation of para-hydrogeologists through exposure and informal training to community members having inherent understanding of spring flow behavior, will help other villages to identify their spring-sheds and manage their spring waters forever growing water demand.

Following are the specific objectives of the PDS:

- Creation of web-enabled database of the springs emerging in the catchment based on extensive inventory of physical and hydro-chemical characteristics.
- Mapping of vulnerable springs using hot-spot analysis.
- Hydrogeological investigation of some selected springs, which are vulnerable and having high societal importance for identification of their spring-shed area and potential.
- To suggest adaptive strategies for selected hot-spot springs for spring sanctuary development to sustain the local water demand.
- To build capacity among the local stakeholders through creating para-hydrogeologists for conserving and managing the springs.

2. REVIEW OF LITERATURE

2.1. General

Springs are critical and dependable sources of water security for the population of mountainous regions across world (e.g. India, USA, New Zealand, Ethiopia, Turkey, Spain and Greece). serve as the primary source of water for millions of inhabitants in the mountain ranges across the India. A gross estimate of nearly 200 million Indians depends on spring water –mainly in the Indian Himalayan Region, 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 Vindhya mountains). The Indian Himalayan Region (IHR) is an ecosystem that spans over 5,37,435 km² (comprising about 16.3% of India's total geographical area) and is home to a diverse range of flora and fauna. 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. However, springs are one of the most cost-effective ways to provide relatively pure water in entire stretch of Indian Himalayan Region (IHR) as rivers are flowing in the deep valley and glacier are far flung, so water from these two sources is economically not feasible. In addition to this, these springs sustain several rivers, particularly in the lean season and there is hardly any River throughout the globe which is not feed by a spring.

2.2. Spring Studies

In this chapter the studies on springs are broadly categorized viz., international level and national level and described as below.

2.2.1. International level

The utilization and tapping of spring water is an ancient art. Historically, to have easy access to water, cities were often situated near large springs, while those cities without a reliable water supply were destroyed (Kresic and Stevanovic, 2010). A systematic process of identifying the type of springs and characterizing them on the basis of their type, discharge quantities, seasonal factors and water quality is the way forward towards improved spring-water management. In 1674, Perrault was one of the prominent thinkers

who began to consider the source and movement of groundwater. Based on his experiments and observations, he argued rainwater was a catalyst for the movement of groundwater, but was not the origin of springs. He likened springs to daughters of rivers. By the 20th century, several researchers classified the springs based on spring flow (Bryan, 1919), geo-hydrological conditions (Perez, 1996) and mean discharge (Meinzer, 1923). However, there has been no consistent and comprehensive classification system or common classification for springs. Springer and Stevens (2008) defined 12 spheres of discharge, describing their hydrogeology of occurrence, and the microhabitats and ecosystems they support.

De Buchananne and Richardson created an inventory on minimum, maximum and average flow of more than 960 springs from east Tennessee. The Springs Stewardship Institute keeps building their online resources. They now have 140,000 springs mapped in western US in their database. ICIMOD (2015) reported that, in the Nepali mid-hill region, a combination of biophysical (e.g., climate variability, changes in land use) and socioeconomic (e.g., spring maintenance) factors were responsible for the drying up of springs. Very limited studies have been conducted so far to make these springs dependable sources of water to the local inhabitants due to paucity of data on spring. Identification of possible recharge area is the most important step towards the development of a spring. The use of isotopes for hydrological research was introduced in the 1960s, mostly along with other methods, to understand recharge and residence times (Kendall and Caldwell 1998; McDonnell 2003; Vitvar et al. 2005; Rai et al., 2011, Kumar 2013). Globally, many studies have used different isotopes for their research objective. Mustafa et al. (2015) studied the $\delta^{18}\text{O}$ and $\delta^2\text{H}$ composition in eight springs to distinguish spring origins, and identified three aquifers in the region: Behkme aquifer, Kometan aquifer and Shiranish aquifer, contributing to spring flow. Lambán et al. (2015) used $\delta^{18}\text{O}$ and $\delta^2\text{H}$ to delineate recharge areas for springs in the Ordesa and Monte Perdido National Park (Northern Spain).

2.2.1. National Level

2.2.1.1. *Spring inventorization*

Not much is known about the quantitative and qualitative aspects of springs in general and Himalayan springs in particular. Except for isolated attempts of inventorization of springs, no regional or national level atlas of springs has been prepared. Only a few scattered attempts of block-level, tehsil level or district level inventories of springs.

However, based on the spring density (2 to 5 springs per km²) and spatial extent of mountain ranges, it has been reported that there are about 5 million springs in various mountain ranges in India. The Sikkim government has initiated a spring mapping and development program through “DharaVikas” and prepared a database on 1600 springs. Bartarya, (1989) identified 1,057 springs in the Gaula catchment and developed an inventory of 88 springs in the Gaula catchment, Nainital district, Uttarakhand. CHIRAG (2018) prepared an inventory of about 1000 springs of the Kumaun region of Uttarakhand. National Institute of Hydrology (NIH), Roorkee, has also developed a comprehensive spring database including hydrological, social, demographical, physical and chemical aspects of about 950 springs in Ravi River catchment, Himachal Pradesh (Figure 2a), 500 springs in Tawo catchment of J&K and about 778 springs located between Satara and Belgaum districts in the Western Ghats. Union Tribal Affairs Ministry launched the “1000 Spring Initiatives” programme and an online portal on GIS-based Spring Atlas with hydrological and chemical properties of the Springs for Odisha. Govt. of Meghalaya - Capacity Building for Spring Revival: initiated work to map 60,000 springs and create a first-cut plan for spring water management on 5,000 springs in 11 districts over the next four years. Rural Development Department, Government of West Bengal - Springshed Management in the Hill Districts of West Bengal: initiated a pilot on 631 springs in four hill districts of Northern Bengal. National Mission on Himalayan Studies: Mapped more than 3000 springs by different agencies in different Himalayan states under the project

2.2.1.2. Magnitude of drying of the springs in IHR

In the last two decades, numerous springs have either dried-up or become seasonal, mainly due to anthropogenic activities in the entire region of Himalaya (ICIMOD 2015). Increasing population and unplanned development have adversely affected the recharge process and resulted in depletion of this prime water resource in the entire Himalayan region. Furthermore, depletion of these springs is also exacerbated by rising air temperatures, late monsoons, and in general, the erratic and torrential rainfall that has replaced the monsoon drizzles of yore. Following are a few snap shots that highlight the magnitude of drying of springs in the IHR:

Natural stressors (especially climate change) and improper watershed management have led to a decrease in discharge in many Himalayan springs (Agarwal et al. 2012). For example, Valdiya and Bartarya (1989) reported a 40% reduction in spring discharge over a 35-year period (1951 to 1986) in the Kumaon Himalaya region, which was mostly attributed to changes in land-use patterns and vegetation. Study conducted in the Kosi basin in the lesser Himalaya of India on 116 perennial springs in the watershed in 1990, out of which 28 have gone dry, and 28% springs have become seasonal till 2010. It has been felt that spring discharges are declining throughout the Lesser Himalayan region. The extent of decrease in discharge was found to be between 25% to 75% in past 5 to 50 years in Uttarakhand region, causing transformation of perennial streams into seasonal (Rawat et al., 2016). In order to drying up of natural springs, the streams depicting decreasing trends of annual discharge and becoming perennial to seasonal streams in the study area. In eastern Himalayan region, where springs are critically important with almost 80% of rural population dependent on springs for drinking water and domestic requirements, Mahamuni and Kulkarni (2012) identified that nearly 8,000 villages were facing acute water shortage due to the drying up of springs. In India, Sikkim government has initiated spring mapping and development programme through “*DharaVikas*” and database on 700 springs have been kept on web portal. Dhara Vikas (spring-shed development) is a government sponsored program, with the help of NGOs and other institutions, to increase the discharge of springs in rural Sikkim. It is modelled with the idea of protecting a spring’s catchment area and providing recharge of its aquifer. Tambe et al. (2012) observed a 50% reduction in spring discharge in Sikkim within a decade. They also reported that springshed development interventions increased spring flow by 230%. Bartarya (1991) proposed ‘spring sanctuaries’ to enhance recharge to springs. According to this study, spring sanctuaries (ponding structures that are fenced and protected to allow water to recharge springs) need to be placed in hillslopes, ridges, alluvial fans and former landslide scars. Only 30% water sources were in good working condition and recharging properly throughout the year, while 70% sources were in poor working condition and going to dry-up in near future as per survey of seven districts of Himachal Pradesh (Bharadwaj, 2014).

Many studies indicated that the springs are affected by variations in rainfall and anthropogenic activities occurring in the recharge area (Rawat, 2006; Negi 2002; Negi and

Joshi 2004; Rawat et al. 2005; Pant and Rawat 2015). Negi et al. (2007) evaluated relationships between rainfall, physiography, lithology, slope and aspect, land-use practices, vegetation, altitude, soil type, anthropogenic interference, and water yield and quality of twelve Himalayan springs. Jeelani et al. (2010) used $\delta^{18}\text{O}$ tracers to identify recharge areas in the Liddar watershed, western Himalaya. Water samples were collected from 6 springs, 14 streams, and 8 precipitation sites for over a year (January 2008 to 2009). In a study in Uttarakhand, India, Deodhare et al. (2014) identified the effect of altitude on spring behaviour, and guided the introduction of new recharge structures. Their results showed that the recharge structures introduced in two springs increased spring discharge by 72% and 145%. Climate change is accelerating the drying rate of these springs due to erratic rainfall resulting in inadequate recharge of aquifers. In last two decades (1990-2010), number of rainy days and annual rainfall has decreased by 0.72 days/year and 17.77 mm/year in Sikkim (Tambe et al., 2011).

2.3. Conclusion from Review and Literature

Most of the studies on springs by different research organizations, universities and NGOs till date are few and scattered, much localized and data collection is for short durations (project period) and discontinued after the project tenure. For this reason, a systematic database/inventory on springs was not generated in the country, due to which these vital water resources could not be part of our National Water Policy. Furthermore, non-availability of basic data makes it extremely difficult to quantify as well as estimate the dependability of these water sources and also puts hurdles in front of state level implementing agencies in crafting action plans for fulfilling local water demand. A successful attempt at transforming springs as dependable water sources for local population has been carried out in Sikkim. However, Sikkim State is geographically very small (7096 km²), has low population density (86 per km² as per 2011 census) and high annual average rainfall (2739 mm), making it unlike the western Himalayan states having districts bigger than the whole of Sikkim, higher population densities and annual rainfalls hovering about 1000 mm. Therefore, an urgent need to conduct a pilot study on springs in Western Himalaya was felt before initiating a program for inventorization and revival of springs across the IHR or at Pan India scale.

3. STUDY AREA

3.1. General

River Ravi, one of the six rivers of the Indus Basin system, originates from the Bharabhangal glacier in the hill state of Himachal Pradesh has a total length of about 720 km and a catchment area of about 14,442 sq km before joining the River Chenab in Pakistan. Ravi River has been allocated to India under the Indus water treaty (IWT). The Ravi River is an important river of Chamba district of Himachal Pradesh. With a catchment area of approximately 5168.03 km², it is situated between 32.179° to 33.025° N latitudes and 75.788° to 77.079° E longitudes. The altitudinal range of the catchment varies from 467 to 5872 meters above mean sea level. The Ravi River starts its journey at an altitude of around 4240 meters above sea level in Bara Bhangal, around 150 kilometres northeast of the historic town of Chamba. Its path is characterized by a steep gradient, featuring numerous twists and turns. Along the way, significant tributaries such as Kalihan, Budhil, Tundah, Seul, and Baira add substantial runoff to the Ravi's flow. Bara Bhangal is surrounded by snow-capped peaks ranging from 3050 meters to 5800 meters above sea level. The river generally flows northwestward, originating in Baira-Balsio, passing through Traila and Chhanota before reaching Ulansa, where it merges with two major tributaries, Budhil and Tundah. From Chhatrari onwards, the river navigates through a narrow gorge before widening. It passes through several towns including Churi, Bagga, Mehla, Chamba, and Udaipur, eventually reaching Rajnagar and then narrowing again towards Sherpur. The Siul River, its largest tributary, joins upstream of the Chamera Stage-I Dam, while the Sewa River meets near Khairi. Continuing southwestward, the river delineates the border between Chamba and Jammu and Kashmir, ultimately exiting Himachal Pradesh upstream of the Ranjit Sagar Dam in Punjab. Budhil nallah originates near Kugti pass in the mid-Himalayas and receives a small stream from the sacred Lake of Mani-Mahesh at Hadsar. It then flows past Bharmour village before meeting the Ravi near Kharamukh. Tundah nallah begins at Kalicho top Pass, traverses Tundah valley, and joins the Ravi downstream of Kharamukh. Generally, the right bank tributaries carry more water compared to the left bank ones, with Kalihan being an exception as it originates in the Dhauladhar range on the left bank and contributes significantly to the flow. Both Budhil

and Tundah are approximately 54 kilometers in length each (Central Electricity Report, June 2004).

This abundance of springs makes the Ravi River Catchment an important source of freshwater for the region and a significant area of study for hydrological research. Initially the study was taken Ravi River catchment up to Chamba town (outlet at *Balu* bridge, drainage area about 3100 sq. km), depicted as Study Area Phase-1 in the Fig. 3.1. However, in view of the progress of the PDS during 6th R&D session, sub-committee on PDS has recommended to take entire Ravi River catchment fall in Himachal Pradesh (drainage area about 5200 sq. km.) as study area depicted as Study Area Phase-2 in the Fig. 3.1. The study area encompasses most of the parts of the Chamba district and a small portion of district Kangra of Himachal Pradesh. The Ravi has some major left bank tributaries such as *Budhil Nallah*, *Tundah Nallah*, *Reshai Nallah*, etc. Its right bank has fewer tributaries such as *Salun Nallah*, *Balani Nallah*, etc., which are either having low discharge or are seasonal. Some of the famous tourist hill station (Dalhousie and Kahjjiar) also lies in the Ravi River catchment.

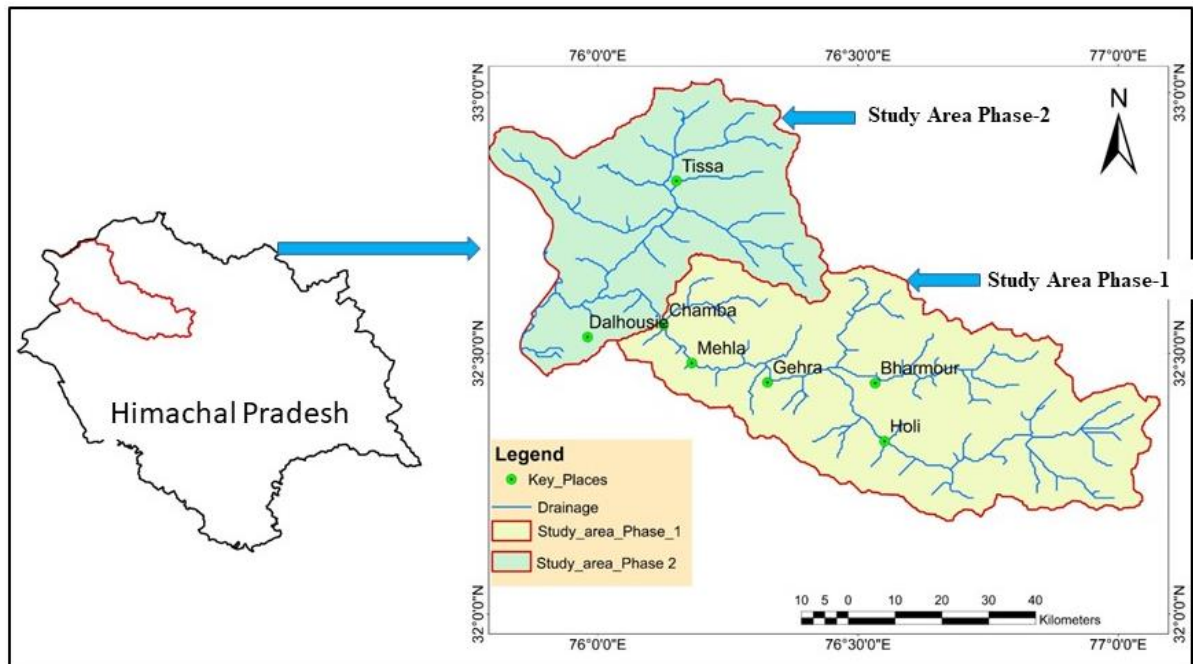


Fig. 3.1 Study area location map of Ravi catchment.

3.2. Physiography of Ravi catchment

The Ravi River basin showcases several notable physical characteristics. It predominantly flows in a North-West direction, originating from Baira-Balsio and passing through Traila and Chhanota before reaching Ulansa, where it merges with two major headwater tributaries, Budhil and Tundah. Beyond Chhatrari, the river flows through a narrow gorge before widening. The basin is marked by an intricate network of valleys and ridges, shaped by geological processes such as erosion, faulting, and sedimentation. The terrain surrounding the Ravi River basin exhibits a wide range of landforms, including terraces, floodplains, and escarpments, which influence the river's flow dynamics and sediment transport. The Ravi River basin supports diverse ecosystems, ranging from alpine meadows and coniferous forests in the upper reaches to subtropical forests and agricultural lands in the lower valleys. Human activities such as agriculture, forestry, and urbanization have significantly modified the landscape of the Ravi River basin, leading to changes in land use patterns, water quality, and ecological balance.

3.3. Geological Setup

The Ravi catchment is situated within the broader geological context of the NW Himalaya, specifically in the region encompassing the Chamba Nappe (Joshi et al., 2022). This geological structure, oriented in a northwest to southeast direction, comprises weakly metamorphosed sedimentary rocks ranging from Late Precambrian to Lower Triassic in age. It is positioned between the PP-range to the north and the D-range to the south ([Rattan, 1973](#); [Thakur, 1998](#); [Sharma and Bhola, 2003](#)). The northern boundary of the Chamba Nappe is delineated by the Chenab Normal Fault, while the southern boundary is marked by the Main Central Thrust, also known as the Panjal Thrust ([Thakur, 1998](#)). The contact between the D-range and the overlying Salkhala Formation is characterized by the Chamba Thrust, which runs parallel to the Ravi River in a northwest to southeast direction ([Singh, 2012](#)). The geological succession within the Chamba Nappe includes the Salkhala Formation (comprising quartzite and schist), the Chamba Formation (alternations of metagreywacke and slate), the Salooni Formation (consisting of slate, basalt, and limestone), and the Kalhel limestone ([Rattan, 1973](#), [Thakur, 1998](#)). The southern boundary of the D-range is defined by the closely spaced Main Boundary Thrust (MBT) and Main Central Thrust (MCT) ([Thakur, 1998](#)). The regional geology of the Ravi River Basin in Himachal Pradesh is characterized by a diverse range of rock formations spanning from

early Proterozoic to Mesozoic age. Slate, phyllite, schist, siltstone, quartzite, limestone, and magnesite are among the prominent rock types found across the basin. The Vaikrita Group dominates certain areas, while formations like the Manjir Formation, Katarigali Formation, and Salooni Formation contribute to the geological diversity of the region. Additionally, granite gneiss and granite underlie significant portions of the basin, while formations such as Shiwalik, Mandi, Karol, Dauladhar, and Zulughz are also present in specific areas (Fig. S1). This varied geological composition not only shapes the landscape but also influences hydrological patterns and environmental characteristics throughout the Ravi catchment.

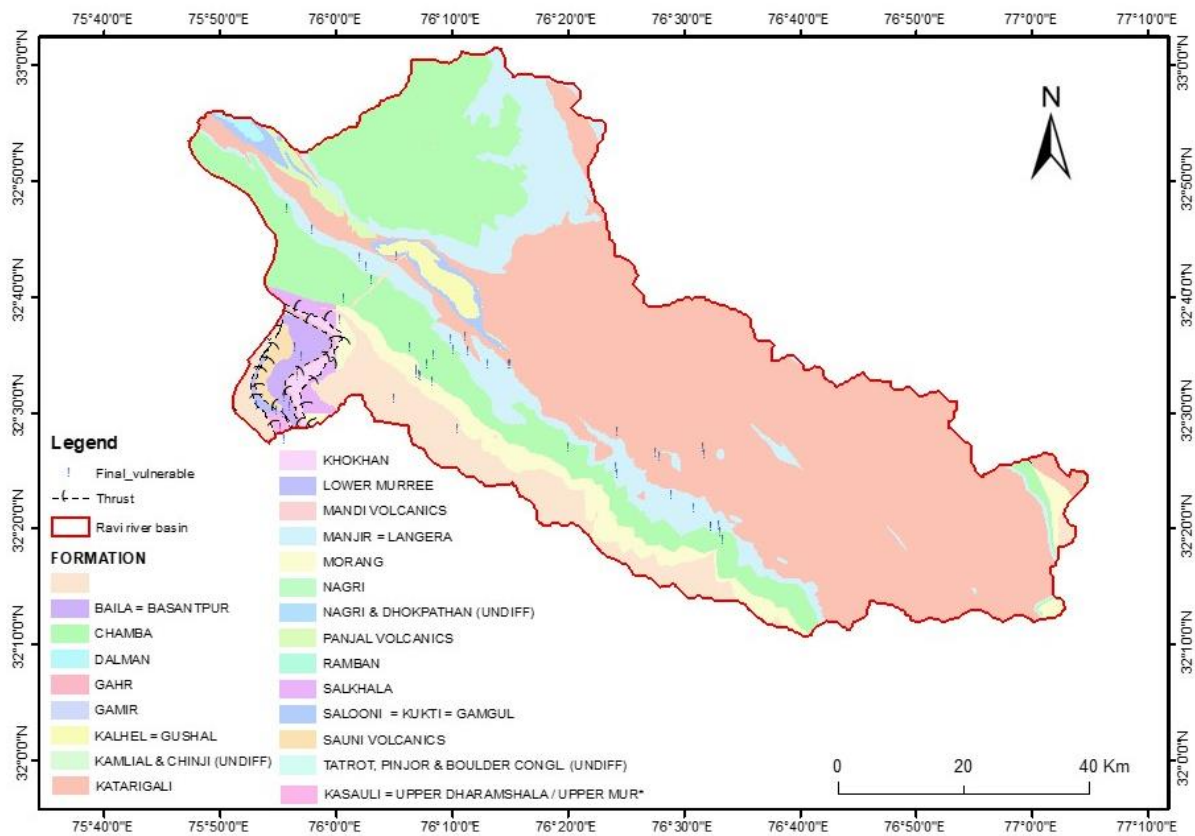


Fig. 3.2 Geological map of the Ravi River basin. Modified after Webb, (2013); Thakur et al., 2019; Srikantia, and Bhargava, (2021).

3.4. Climate

As the Ravi River basin is wholly mountainous, with altitudes ranging from 559 meters to 5563 meters above mean sea level, a variety of climate is found from the semi-tropical to the semi-arctic. In the lower part of Bhattiyat tehsil, the climatic conditions are similar to those of Kangra and the Shivalik area. The temperature begins to increase rapidly

after the middle of April and this rise continues till the break of rains in July. In the Ravi valley the climatic conditions vary with altitude. In the lower portion of the valley from the capital downwards they are semi-tropical. The heat is there and the rainy season well marked, while winter is mild and the snowfall light.

In Bharmour, Holi and Bara Bhangal area summer is exceedingly mild and pleasant. Owing to the scarce rainfall the percentage of humidity is always low. The winter is very severe and snowfall starts in October and continues till March and April. The district is having rainy season from middle of June to the middle of September and has vastness of the rainfall during this season. Snow may fall as early as the beginning of October. The snowfall on the Dhauladhar and Pirpanjal range is heavy and in severe winter it lasts from the early November to late March (Census report, 2001).

The rainy season is heavy and prolonged in Ravi River basin in H.P. The basin is having rainy season from the middle of June to the middle of September and has bulk of the rainfall during this season. Table 3.1 shown the monthly rainfall at 08 raingauge stations of Ravi River catchment.

Table 3.2 Monthly rainfall data at different rain gauge stations of Ravi River catchment.

Months	Chamba	Bharmour	Tisa	Bhandal	Kalatop	Saloni	Kheri
1	2	3	4	5	6	7	8
January	13.0	64.4	96.6	98.0	15.0	106.6	86.4
February	169.0	119.9	246.1	351.0	165.0	308.0	252.8
March	89.0	140.7	197.2	387.0	272.0	276.1	319.4
April	23.0	81.2	98.1	221.0	158.0	162.0	108.8
May	30.0	14.7	21.8	48.0	45.0	32.0	24.0
June	69.0	90.0	91.4	17.0	200.0	121.5	89.4
July	214.0	229.3	318.3	-	284.0	333.0	474.8
August	140.0	50.3	206.2	-	172.0	151.7	538.2
September	55.0	0.0	69.8	-	80.0	160.0	219.8
October	0.0	18.4	81.5	-	13.0	15.5	55.0
November	31.0	19.6	34.8	-	6.0	44.0	14.0
December	53.0	20.2	48.7	-	54.0	87.5	24.4

Source: Meteorological Centre Shimla, Himachal Pradesh

Though July and August months are wettest months yet rainfall in the months of January and February is also significantly high in the basin. South and western Chamba area receives more rainfall than north and eastern Chamba area in this basin. Normal annual rainfall in this basin is 1,741 millimeters.

4. METHODOLOGY

4.1. Strategy, Planning and Execution of Survey for Creation of Spring Inventory

The springs could not find due importance so far in our policy due to lack of scientific database on springs in the Himalayan region. Local people understand their importance in their daily life but due to lack of readily available information, these springs always faced negligence at policy level as well as execution level. Spring inventorization is a step towards building the primary database on springs along with geo-tagging of springs. Geo-tagging of a spring helps to identify the actual location of spring to make periodic monitoring possible. Especially, any anthropogenic activity in the recharge area can be traced through remote sensing and GIS techniques.

4.1.1. Spring data format

Spring mapping is required for four broad purposes viz., (i) Geotagging of springs using GPS, (ii) collection of information pertaining to the various characteristics of the spring, (iii) analysis of various physical parameters (Taste, colour, odour, pH, EC, discharge) in the field and (iv) collection of samples of spring, rain and local water bodies for chemical and isotopic analysis. Based on these purposes a data collection Format pertaining to the various general and important parameters for springshed management has been devised. The various parameters collected during the mapping of springs are given in the Table 4.1.

In phase-1 geotagging was carried-out by a cam-based GPS (Fig. 4.1) while data collection format was filled manually on a paper sheet. However, in view of the manual errors encountered during the survey of phase-1 and restriction of movement in interstate due to COVID-19, survey of study area of phase-2 was carried-out through a mobile app. It also significantly reduced the tedious work involved in digitization of manually filled survey form. Therefore, a mobile app was developed in KoBo tool box (open-source platform, Fig 4.2) which has capability to geotagg of springs and also has options to customize the prescribed survey form. Additionally, app has capability to map the springs in offline (non-availability of network) mode and stored data can be pushed to the admin while network is available.

Table 4.1 Parameters collected during the survey and mapping of springs in Ravi river catchment.

Sl. No.	Parameters	Sl. No.	Parameters
1	Spring name	12	Type of land use above the spring (Agriculture/Forest/Barren/Pastures/Mountainous/Built-Up)
2	District/Tehsil/Gram Panchayat/ Village	13	Dependency (High/Medium/Low)
3	Spring type (Nadu/Bawali/Paniyara)	14	Spring water usages (Drinking/washing/Bathing/Cattle)
4	Spring nature (Perennial/Seasonal)	15	Spring discharge (LPM)
5	Latitude & Longitude	16	Spring discharge trend
6	Elevation (m, amsl)	17	Water conflict
7	Spring Geo-tagged Photo (Close, wide angle and selfie)	18	Peak/Lean month of discharge
8	Dependent (Village/Household/Livestock)	19	Colour/Odour/Taste
9	Other water source in the Village (Pipe water/Gadhera/Spring)	20	Temperature of Spring Water ($^{\circ}\text{C}$)
10	Name of gram pradhan	21	Water Quality Parameters. 14 nos. (pH, EC, Ca^{+2} , NO_3^{+} , SO_4^{-} , F-, SiO_2 , K+, Fe, Na+, Cl-, HCO_3^{-} , CO_3^{-2} and alkalinity)
11	Spring ownership (Private/Government)		



Fig. 4.1 Geo-tagged springs of Ravi river catchment using Cam-based GPS.

4.1.2. Digitization of springs from toposheet

Since, no database on spring particularly Ravi River catchment is available, the springs shown in the Survey of India toposheets (Year 1971) were digitized. It gives an idea about the spring density in the catchment which is helpful in deciding the deployment of the project staff in the catchment. Twelve toposheets (1:50000 scale) of Survey of India (52D2, 52D6 52D16, 52D10, 52D15, 52D3, 52D7, 52D11, 52H3, 52D12, 52H2 and 52H4) which comprising the Ravi River catchment up to Chamba town were first geo-referenced and then mosaic (Fig. 4.3). Streams and the springs marked in the toposheets were digitized. Total 178 springs have been identified in SOI toposheets for Ravi river catchment for the study area taken in Phase-1 (i.e., up to Ravi River catchment up to Chamba town). Figure 4.4 depicted the springs and streams in the Ravi River catchment up to Chamba town.

The figure displays four sequential screenshots of a mobile application interface, likely for data collection in a field setting. Each screen has a header bar with a blue icon, the text "Chamba-HP-ISHV...", and standard mobile UI icons (save, back, and menu).

Screen 1: General information

- Name of the surveyor
- Spring ID
- Village
- Gram Panchayat
- District
- Spring Name
- Spring Type
- Select One Answer
- NEXT >

Screen 2: Discharge

- Volume of water
- Time taken to collect the water (enter the time in seconds)
- Dependency on spring water (High, Medium, Low)
- Usage of spring water
- Select Answer
- Water conflicts
- Select One Answer
- Months of peak discharge
- Select Answer
- Months of lean discharge
- < BACK
- NEXT >

Screen 3: Spring location and information

- * GPS Coordinates
- Start GeoPoint
- Spring photo
- Take Picture
- Choose Image
- Landmark
- Total number of dependent villages
- Name of dependent villages
- Total number of dependent households
- < BACK
- NEXT >

Screen 4: Other information

- Name of information provider
- Contact number of information provider
- Date of survey
- Select date
- No date selected
- Select time
- No time selected
- Name of gram pradhan
- Contact number of gram pradhan
- Water sample collected
- < BACK
- NEXT >

Fig. 4.2 Snapshot of the developed Mobile-app in KoBo tool box.

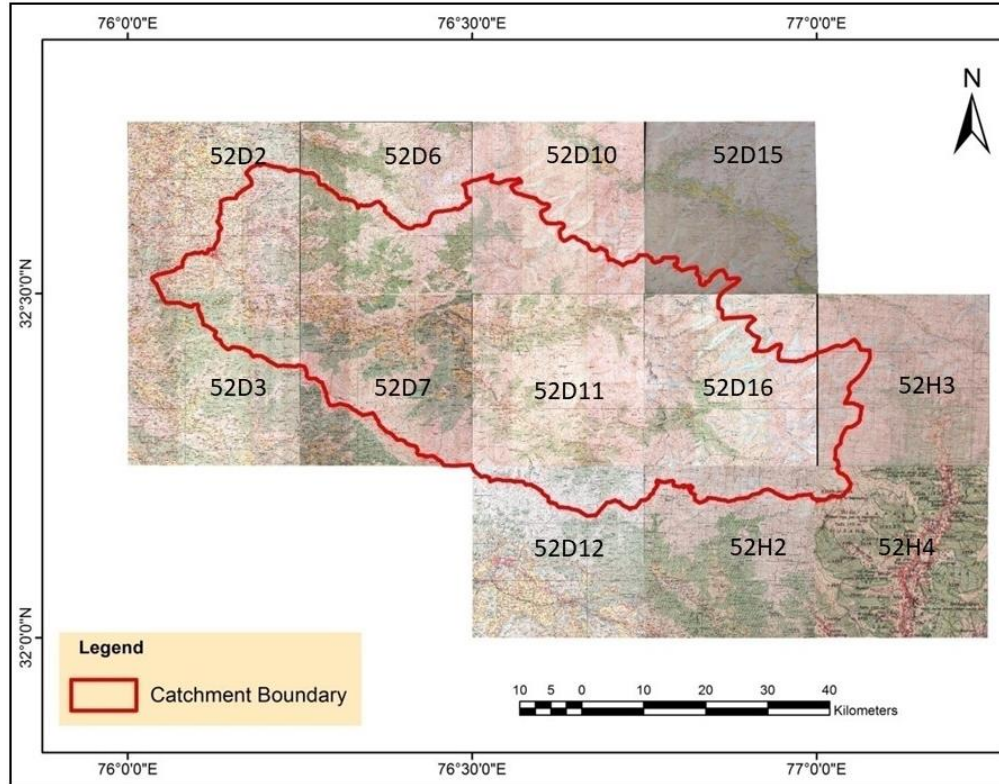


Fig. 4.3 Mosaic of toposheets of the study area for digitization of springs demarked in the toposheets in Ravi river catchment up to Chamba town (study area taken under phase-1).

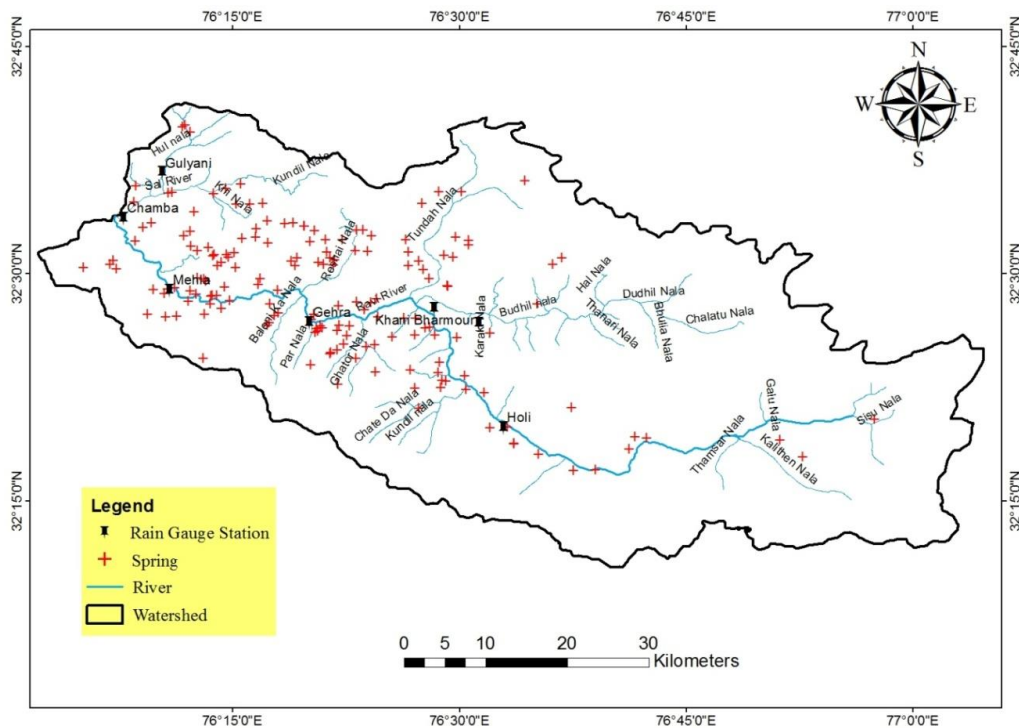


Fig. 4.4 Springs and major streams digitized from SOI toposheets.

Based on spring density and distribution of springs in the catchment, entire catchment has been divided in the four zones (Fig. 4.5). Zone 1 is the downstream part of the catchment and comprising the Chamba town and its nearby villages. Total 41 springs from SOI toposheets have been identified in this zone. This zone comprising villages located in both left and right side of River Ravi while Sal River is one of the major tributaries of the Ravi falls in this zone. zone 2 is the upstream of zone 1 and comprises 75 springs as per SOI toposheets. Baloni nallah and Rosnai nallah are the major tributaries of Ravi in this zone. Zone III is the catchment of Budhil nallah which is one of the major tributaries of Ravi river and join Ravi at Kharakmukh. Tundah nallah is other major tributary of Ravi flow in this zone. Bharmour is the major settlement in this zone and it is also main stay place for *Manimahesh* pilgrimage. Zone 4 is the uppermost part of the Ravi and most of the part is snow covered during winter months. Holi is the major settlement in this particular zone.

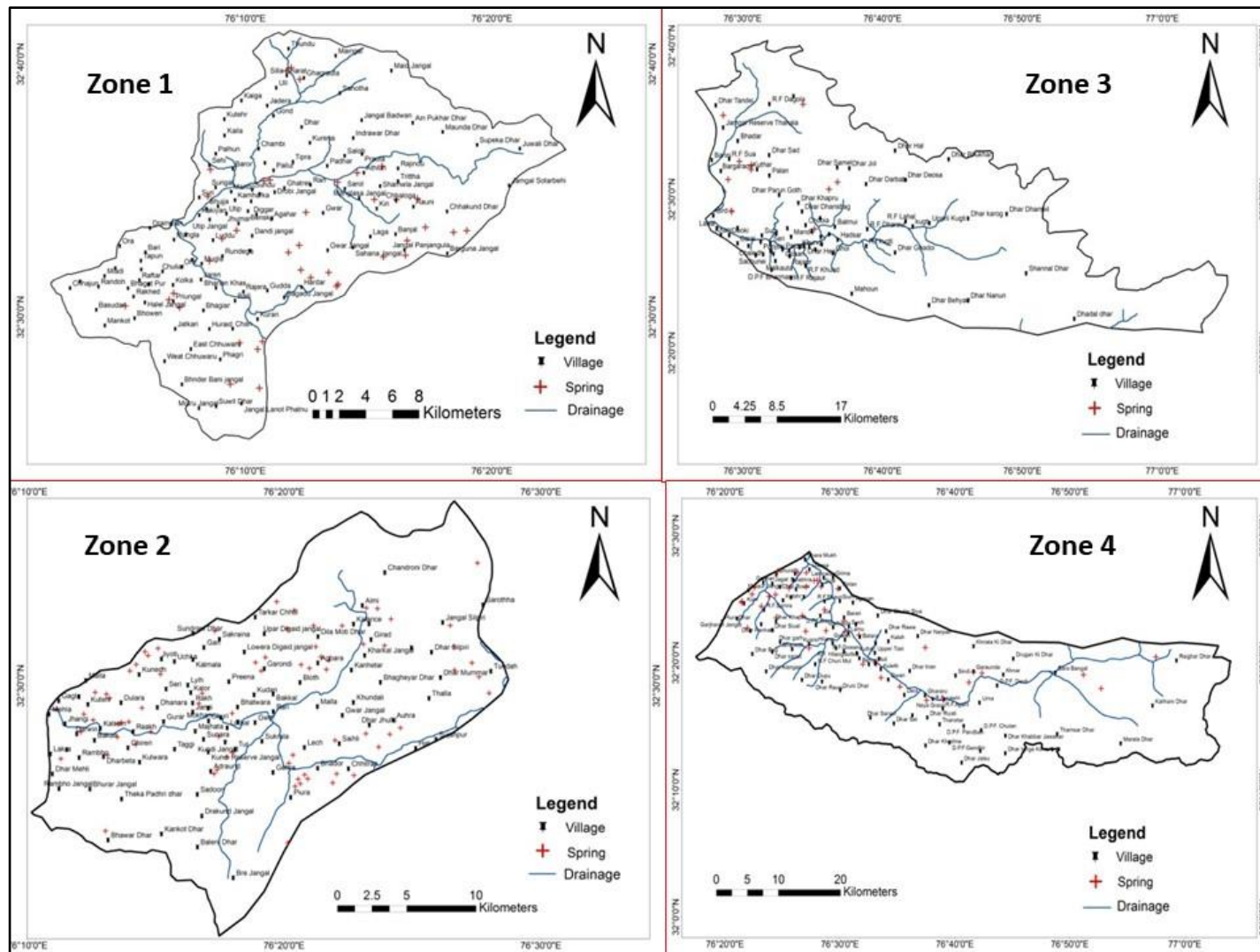


Fig. 4.5 Division of study area in four zones for conducting the survey of springs.

4.1.3 Conducting the Survey

To conduct the survey of springs, in each zone one field assistant has been deployed. Each field assistant is equipped with one GPS (in-built Camera of 8 megapixels) and one set of HACH-USA made pocket type pro pH and EC meters (Fig. 4.6) for measuring pH and electrical conductivity, respectively in in-situ condition. Maps which containing various information related to location of villages nearby springs, streams, springs demarcated in toposheets, roads network, land use etc have been prepared and training has been given to each all-field assistants to get well acquainted with the field to be surveyed (Fig. 4.7). First, spring photo is clicked by the concerned field assistant and then provide a particular code for geo-tagging of the spring. A questioner (Table 4.1) comprising the information on different aspects such as hydrology, chemistry, demography, water dependency and water utilization etc. will be filled by the concerned field assistant by conducting the interview with the actual water user of spring.



Fig. 4.6 Field assistant equipped with cam-based GPS and pocket type pro pH and EC kit deployed in different zones of Ravi River for conducting spring survey.



Fig. 4.7 Training of field staff to get well acquainted with the study area for making survey strategy for mapping of springs of the area.

4.2. Field Measurements and Analytical Procedures

4.2.1. Field Measurements

(a) Geographical Locations

Geographical location including latitude-longitude and elevation (amsl) were acquired using hand held Garmin Etrex Global Positioning System (GPS). It works with vertical and horizontal accuracies of ± 15 m and ± 3.9 m, respectively.

(b) Physical Parameters

Measurement of parameters such as pH, temperature, EC and ORP were carried out onsite using portable measuring kits of Hach, USA make HQ40d handheld multimeter (Fig. 4.8). Prior to use, the instruments were calibrated with given buffer solutions of known pH (4.01, 7.0 and 10.0 of Merck ®) and EC (1413 $\mu\text{S}/\text{cm}$ KCl in-house solution and 1000 $\mu\text{S}/\text{cm}$ NaCl solution of Merck ®).



Fig. 4.8 Onsite measurement of physical parameters of spring water.

4.2.2. Laboratory Analysis

(a) Carbonate and Bicarbonates

The samples stored in 250 ml high-quality polyethylene Tarson bottles were used for carbonate (CO_3^{2-}) and bi-carbonate (HCO_3^-) analyses on auto titrotor of Tarsons Titertop 25. 0.02N Sulphuric acid (H_2SO_4) was used to carry out the measurement. 25 ml of each sample was taken for analyses followed by the repeated analysis of few randomly selected samples to maintain the accuracy of the results. The amount of acid consumed to neutralize the sample was noted and further used to calculate the concentration of CO_3^{2-} , HCO_3^- and alkalinity.

(b) Major Ions

The ions present in the water in significant concentration are considered as major ions. These include both anions and cations. These include Fluoride (F^-), Chloride (Cl^-), Sulphate (SO_4^{2-}), Phosphate (PO_4^{2-}), Nitrite (NO_2^{2-}), Nitrate (NO_3^-), Sodium (Na^+), Potassium (K^+), Ammonium (NH_4^+), Magnesium (Mg^{2+}) and Calcium (Ca^{2+}). The samples were analysed using Ion-Chromatograph (DIONEX ICS-5000). De-ionized water with a resistance of $18.2 \text{ M}\Omega$ was used for the preparation of all the solutions and dilution of water samples wherever required. Working solution for anions and cations were prepared by the dilution of salt standard (stock solution of 1000 ppm) of Merck®. The techniques used during the analysis are the standard methods of water analysis specified by the American Public Health Association (1975, 1995). 5ml of each sample were diluted 10 times with Milli-Q water to bring the ionic concentration in the sample within the sensitivity of the instrument and the results were reported with an uncertainty of $<5\%$. Multiple analyses of few samples were also done to know the uncertainty of the results.

(c) Trace metals

Metals present in minor concentrations in the water are known as trace metals. Exposure to excessive quantities of these can be metals toxic. These include Iron (Fe), Cooper (Cu), Cobalt (Co), Nickel (Ni), Arsenic (As), Silica (Si), Manganese (Mn), Zinc (Zn), Chromium (Cr), Beryllium (Be) etc.

Trace metals were analysed using Inductively Coupled Plasma-Optical Emission Spectrometry ICP-OES (Agilent -5110). Prior to analysis, the ICP-OES was calibrated

with Merck (multi-element) standards to maintain the accuracy of the results. All the results are reported with an analytical precision of better than 5%.

(d) Stable Isotopes

The measurements of $\delta^{18}\text{O}$ and δD were carried out using Delta V Plus IRMS attached with FINNIGAN Gas Bench-II. The instrument was calibrated against International (Primary) standards i.e., VSMOW and GISP supplied by IAEA, and In-house (secondary) standards i.e., MQ and BISLERI. The results have been reported against VSMOW in standard delta notation with reproducibility better than 0.1‰ (1SD) for $\delta^{18}\text{O}$ and 1‰ (1SD) for δD . For collecting samples eight raingauge stations at different altitude ranging from 680 m to 2302 m, amsl were installed in Ravi River catchment (Fig. 4.9) and isotopic sample of rainfall was collected on daily scale.

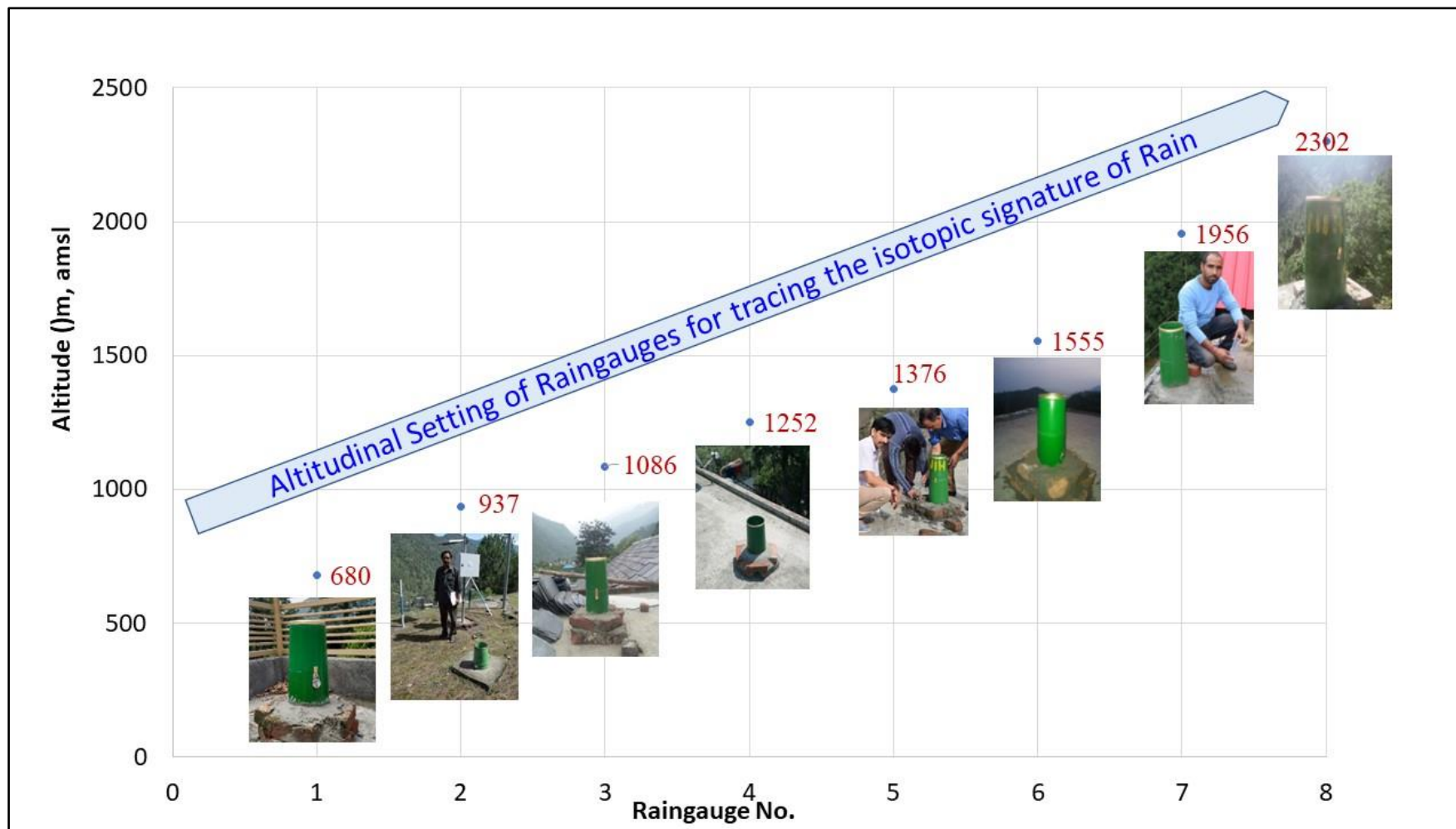


Fig. 4.9 Raingauge station installed at different altitudes of Ravi catchment for capturing the isotopic signature of rainfall of different altitudes.

Stable Isotopes of Oxygen ($\delta^{18}\text{O}$)

About 200 μl of each sample was taken with the help of fixed Auto-pipette and introduced to the 12ml glass vials and closed properly. The vials containing standards and samples were then placed in a thermostatic sampling tray on gas bench. During the whole process, the temperature was maintained at 23°C.

For $\delta^{18}\text{O}$ determination in water, a mixture of He and CO_2 gas (He, 99.9% + CO_2 , 0.1%) is used to flush the atmospheric gases present in the vials. The procedure of flushing takes 12 min for each water sample. After which, the samples were left to equilibrate for 18 hours with the CO_2 gas introduced at the headspace of the vials. The equilibrated CO_2 was then extracted from headspace by introducing 99.9% He gas. The gas mixture was then introduced to Nafion tube to remove the moisture. Once the moisture gets removed, the gas was passed through an isothermal gas-chromatographic column to separate the gases. After the separation, pure CO_2 get released to analyse $\delta^{18}\text{O}$ in IRMS. Several repeat analyses of randomly selected samples were also done in between to maintain the accuracy of the results.

Stable Isotopes of Hydrogen (δD)

The analytical procedure for δD measurement is almost similar to that of $\delta^{18}\text{O}$. For the analysis of δD , a mixture of He 0.05% + H_2 is used for flushing of atmospheric gases from the vials. In addition, platinum electrodes are used that act as a catalyst and reduce the equilibration time of the samples to one hour. The platinum electrodes were introduced to the vials before flushing the vials with the helium gas.

Correction of H_3^+ factor

In water, the abundance of ^2H or deuterium (D) is relatively low as compared with protium. Molecular H_2 is readily used as a reference gas for the measurement of D in high precision instrument, such as IRMS. H_3^+ readily forms in the ion source of mass spectrometer during the measurement of 2H under the following reaction:



Thus, the correction is required to rectify the contribution of H_3^+ from HD^+ .

$$[\text{H}_3^+] \propto [\text{H}_2^+] [\text{H}_2] = K[\text{H}_2]^2 \quad (4.2)$$

Here, the proportionality constant (K) is known as the H_3 factor. H_3^+ correction describes an algorithm applied to measured δD data to correct the contribution of H_3^+

species formed by ionic reactions in the ion source at increasing gas pressures. In IRMS, H_3 factor is calculated automatically using the software ISODAT. The value of K is determined by measuring the mass of H^{3+} /mass of H^{2+} by constantly increasing the pressure.

$$R = R^* + KiH_2 \quad (4.3)$$

where R is the measured ion current ratio, R^* is the corrected HD/H_2 ratio and iH_2 is the ion current due to H_2^+ ion.

Calculation of Isotopic Ratios

Variability of stable oxygen and hydrogen isotopes of natural waters is very low. Therefore, for the convenience of handling and reporting the data, these are reported as parts per thousand (‰) deviations from the standards value. The formula used to calculate the ratios of stable isotopes of oxygen and hydrogen in water is as follows:

$$\delta^{18}O \text{ (‰)} = \left[\frac{(^{18}O/^{16}O)_{\text{sample}}}{(^{18}O/^{16}O)_{\text{standard}}} - 1 \right] \times 1000 \text{ ‰}; \text{ and} \quad (4.4)$$

$$\delta D \text{ (‰)} = \left[\frac{(^2H/^1H)_{\text{sample}}}{(^2H/^1H)_{\text{standard}}} - 1 \right] \times 1000 \text{ ‰} \quad (4.5)$$

A basic water quality Lab was developed under NHP-PDS at Western Himalayan Regional Center (WHRC), Jammu (Fig. 4.10). However, the isotopic analysis of spring and rain water were conducted at Nuclear Lab of NIH, Roorkee. Some parameters such as pH, EC, TDS, DO, ORP and alkalinity were measures in the field using portable probes.

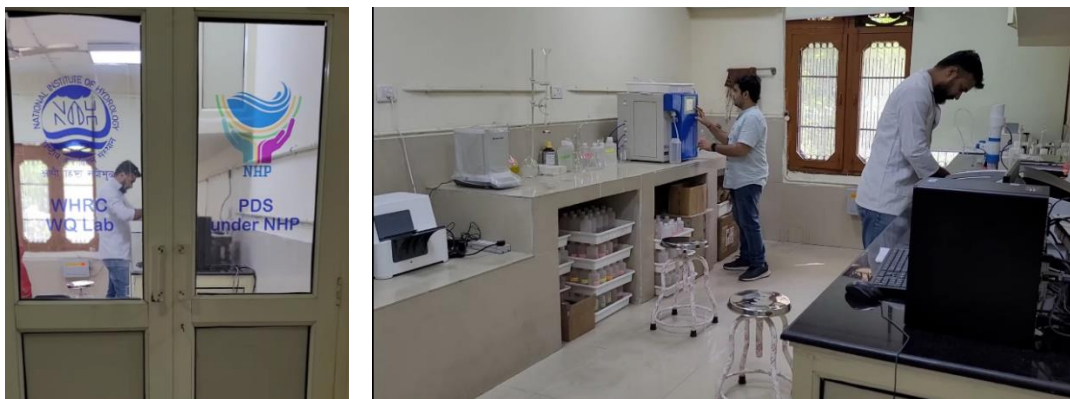


Fig. 4.10 Basic water quality lab established at WHRC, Jammu for spring's water quality analysis.

4.3. Development of Web-GIS based Information System

Modern advancements in GIS, Remote sensing and Internet technologies are also making significant effect on various planning, management and decision support activities in natural resources with a special emphasis in water resource management. GIS provides various means to improve the interpretation and analysis of the existing geographical data which is presently stored by using conventional methods. These new technologies play a vital role in dissemination & distribution of information.

Geographic Information System contains enormous data on geographic, socio-economic, physical, chemical and biological variables across multiple spatial and temporal scales. Web-based Geographic Information System (WebGIS), is a combination of GIS and Internet technologies, is a great choice for creating, storing, accessing and representing multivariate data. WebGIS brings one step closer to visualizing the complex pattern and relationship of heterogeneous data that describes real-world situation in a visual, dynamic and interactive format.

A WebGIS based information system using open-source technologies i.e., Geoserver, HTML, and JavaScript which has capabilities to create, store, access and represent the data in various thematic data layers in GIS environment (Fig. 4.11) and hosted in public domain.

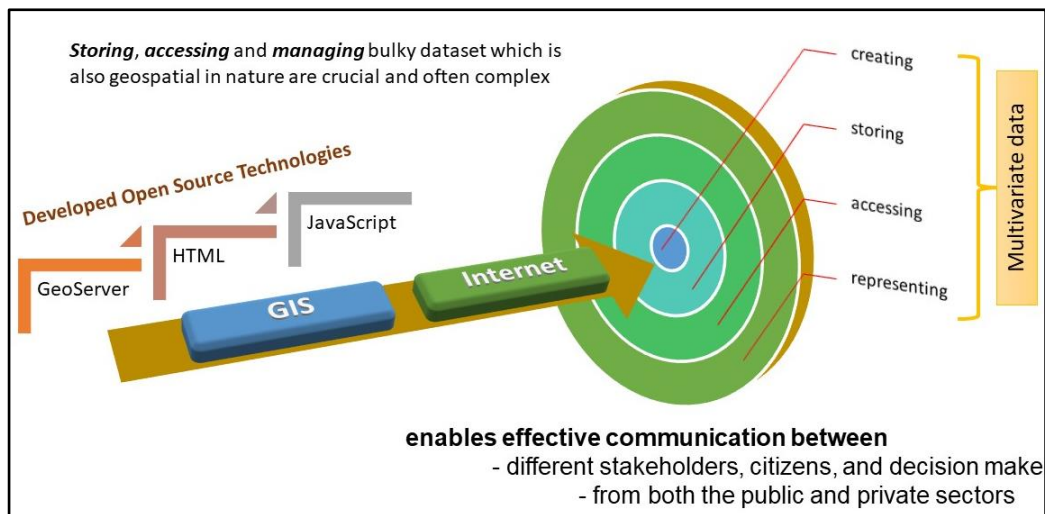


Fig. 4.11 Schematic diagram of Web-based Geographic Information System.

4.4. Vulnerability Analysis

The vulnerability assessment of spring water sources is a crucial endeavor aimed at comprehending the intricate interplay between water quality dynamics and socio-economic factors within a defined geographical area. Springs, being natural outlets of groundwater, hold a significant position in supplying water for diverse needs such as domestic consumption, agricultural irrigation, and industrial operations. This role becomes even more pronounced in mountainous regions, where access to surface water sources might be constrained or impractical. In such landscapes, springs emerge as lifelines, offering a reliable and often the sole source of freshwater for local communities. The sustainability and accessibility of these springs, therefore, directly impact the livelihoods and well-being of the people who depend on them. Understanding the vulnerability of spring water sources becomes paramount in ensuring the long-term availability of clean and reliable water for various purposes. Firstly, springs serve as vital sources of potable water for household consumption, catering to the basic needs of communities residing in the vicinity. Additionally, they fulfill the water requirements of agricultural activities, supporting the cultivation of crops essential for food security and economic sustenance. Moreover, springs often drive small-scale industrial ventures, contributing to local economic development and livelihood opportunities.

4.4.1. Database to evaluate spring water vulnerability

The vulnerability assessment of spring water sources in the study area involved the utilization of several key parameters, each contributing to the comprehensive evaluation of water quality and socio-economic factors. These parameters included:

- a. **Discharge (lpm):** The rate of discharge from the spring, measured in liters per minute (lpm), provided essential data on the availability and sustainability of the water source. Spring having low discharge will have larger susceptibility to dry in the coming years.
- b. **Nature of spring:** The classification of the spring's nature, distinguishing between characteristics such as perennial or seasonal flow, offered insights into its resilience and long-term viability.
- c. **Number of dependent populations:** Quantifying the population dependent on the spring water source helped gauge the socio-economic significance of the spring within the local community.

- d. **Dependency level:** Assessing the level of dependency of communities on the spring water source provided further understanding of the vulnerability of populations to water scarcity or contamination.
- e. **Availability of alternative water sources:** Identification of alternative water sources in the region allowed for an assessment of the resilience of the local water supply network.
- f. **People perception about discharge (Increased or Decreased):** Community perceptions regarding changes in the discharge of the spring water source offered insights into potential concerns or challenges related to water quality and availability.
- g. **pH and TDS:** Measurement of physicochemical parameters such as pH (acidity or alkalinity) and Total Dissolved Solids (TDS) served as indicators of water quality and potential contamination sources.

Each parameter was assigned a rank based on its relative importance and contribution to the vulnerability assessment (rank 3 as “Highly vulnerable”, rank 2 as “Moderately vulnerable” and rank 1 as “Least vulnerable”) (Table 4.2), allowing for a comprehensive evaluation of spring vulnerability and its socio-economic implications. Since every parameter contributed in vulnerability does not have equal weight, experts’ opinion has taken to standardized the weight of each parameter. For this a google form has devised and sent to the experts in the domain for providing the rank of all eight parameters in the sequence of their importance in the making of a spring vulnerable. Based on the responses of the 27 experts of the domain (Fig. 4.12) the weight has been assigned. Calculating a weighted vulnerability index based on the aforementioned parameters provided a holistic assessment of the spring water source's vulnerability to various environmental and socio-economic factors. The integration of these parameters facilitated targeted interventions and management strategies aimed at safeguarding and enhancing the resilience of spring water sources in the study area.

Table. 4.2 Ranks and Weights of parameters for vulnerability assessment of Ravi springs

S. No.	Parameters	Classes	Vulnerability Rank
1	Spring discharge magnitude (Weight = 0.17)	Spring Discharge ≤ 5 LPM	3
		5 LPM < Spring Discharge $\leq$ 20 LPM	2
		Spring Discharge > 20 LPM	1
2	Spring water availability across the year (Weight = 0.19)	Seasonal	3
		Perennial Spring	1
3	Total dependent population on spring (Weight = 0.16)	Dependent Population > 300	3
		50 < Dependent Population $\leq$ 300	2
		Dependent Population $\leq$ 50	1
4	Level of dependence (Weight = 0.14)	Low	1
		Medium	2
		High	3
5	Availability of alternative water sources (Weight = 0.11)	Only Spring	3
		Spring + Pipeline	2
		Spring + Pipeline + Stream	1
6	Variability of spring water flow (Weight = 0.13)	Highly Decreased	3
		Decreased	2
		No Change	1
7	Totally Dissolved Solids (TDS) (Weight = 0.16)	TDS > 300	3
		250 < TDS $\leq$ 300	2
		TDS $\leq$ 250	1
8	pH (Weight = 0.05)	6.5 $\leq$ pH $\leq$ 8.5	1
		pH < 6.5 or pH > 8.5	3

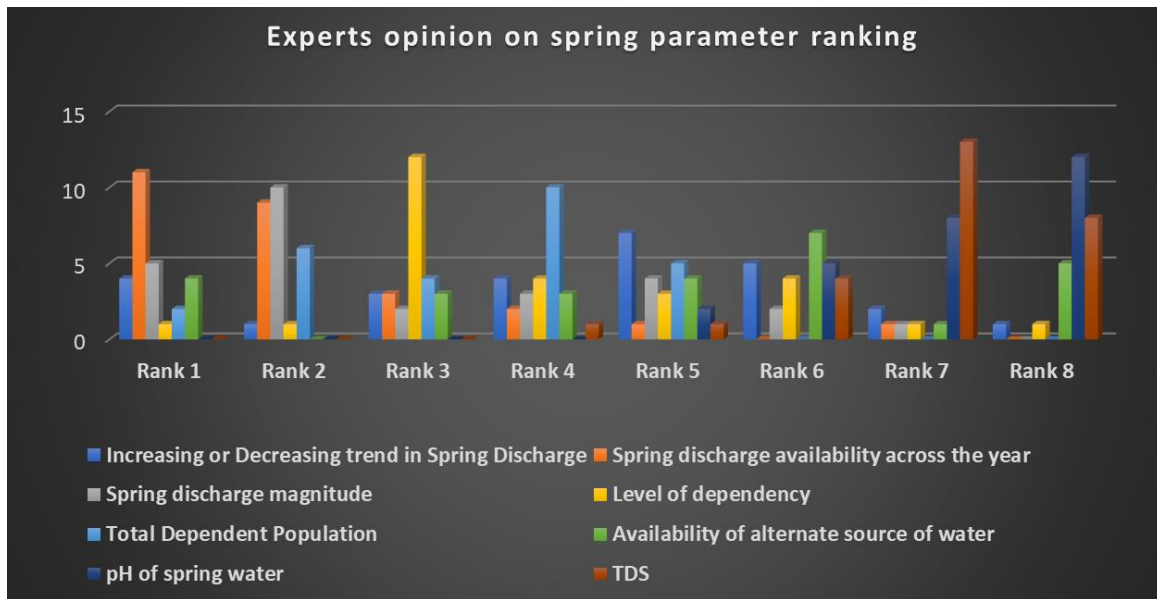


Fig. 4.12 Ranking given by the domain experts to various parameters which contribute in the vulnerability of a spring.

4.5. Hydrochemistry of Springs in Ravi catchment

In the context of the Himalayan catchments, numerous methodologies are available for conducting spring water quality assessments (Taloor et al., 2020; Dumaru et al., 2021), ranging from fuzzy analytical hierarchy processes to multivariate statistical analysis (Thapa et al., 2020; Lone et al., 2021). Among these methodologies, the Water Quality Index (WQI) stands out as the most commonly employed method for evaluating water quality, offering a comprehensive representation of the overall state of water quality (Taloor et al., 2020; Singh et al., 2023). However, conventional WQI approaches have limitations, including an inflexible framework and reliance on subjective parameter weighting (Abtahi et al., 2015; Gao et al., 2020). To address these shortcomings, efforts have been made to enhance the WQI, such as the development of the entropy-weighted water quality index (EWQI), which eliminates subjectivity by incorporating entropy weights (Li et al., 2010). Despite the effectiveness of the EWQI, its implementation often involves analyzing a large number of water quality parameters, which can be time-consuming and costly (Xu et al., 2018). Therefore, there is a need to refine the assessment process by selecting a suitable number of parameters that balance accuracy and cost-effectiveness (Li et al., 2012), especially in Himalayan catchments. Data reduction methods, such as principal component analysis (PCA) and stepwise multiple linear

regression (MLR), can aid in identifying key parameters for constructing more efficient EWQI models (Mu et al., 2024). (Pesce and Wunderlin, 2000). The spring water in Himalayan catchments is crucial for both human consumption and irrigation. There is a clear need for a more comprehensive, accurate, and efficient method to understand and assess spring water quality. Therefore, In the Himalayan catchments, employing data reduction methods for water quality assessment holds promise for enhancing cost-effectiveness and efficiency. By strategically selecting key parameters, researchers can focus on essential indicators tailored to the region's unique characteristics. This streamlined approach reduces resource requirements for sampling, analysis, and monitoring equipment, resulting in significant cost savings, particularly in remote or challenging terrains. Moreover, it will expedite data collection and analysis processes, crucial for timely decision-making in dynamic environments like the Himalayan region. By ensuring that selected parameters accurately reflect water quality dynamics in the catchment, data reduction methods facilitate more informed decisions to safeguard precious water resources effectively. Therefore, there is a need to refine the assessment process by selecting a suitable number of parameters that ensure both accuracy and cost-effectiveness to understand the water status and assess the spring water quality in the Himalayan catchments. Therefore, the objectives of this study in the Ravi catchment area are to: 1) Utilize data reduction techniques (PCA and MLR) to identify key parameters from various spring water quality parameters, to identify the most crucial factors influencing spring water quality, 2) Compare the effectiveness of these reduction techniques with conventional EWQI approaches to determine the optimal model for water quality assessment in the Ravi catchment, 3) Conduct a comprehensive assessment of spring water quality and its spatial variability in the Ravi catchment using multiple methods (EWQI, EWQI_{PCA}, and EWQI_{MLR}), and Depiction of spring water vulnerable zones. By achieving these objectives, this study aims to provide valuable and reliable information for assessing spring water quality in the Ravi catchment area. Furthermore, it seeks to serve as a reference for future studies in the Himalayan region, contributing to the sustainable development of water resources in the region.

4.5.1. Calculations and establishment of the Entropy Water Quality Index (EWQI)

The methodology for establishing EWQI data reduction models involves a systematic approach to assess spring water quality in the study area. Initially, spring water samples are collected from various locations across the study area, ensuring representation of spatial variability. Standardized protocols are followed during sample collection to maintain consistency and minimize contamination (APHA,). Data is recorded for key physicochemical parameters, including pH, total dissolved solids (TDS), Electrical Conductivity (EC), and concentrations of ions such as sodium (Na^+), Potassium (K^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Bicarbonate (HCO_3^-) chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-). Following data collection, an initial quality check is performed to identify and address any outliers or inconsistencies in the dataset. Missing data or outliers are managed through imputation or removal to ensure the integrity of the dataset. Subsequently, data preprocessing techniques such as standardization or normalization are applied as necessary to ensure comparability across parameters.

Principal Component Analysis (PCA) is then employed to reduce the dimensionality of the dataset and identify significant principal components (PCs) that explain the variance in water quality parameters. The suitability of the data for PCA is assessed through the Kaiser-Meyer-Olkin (KMO) test and Bartlett test, ensuring variable correlation and adequacy of the data (Fig. 4.13). The number of PCs retained is determined based on established criteria such as the Kaiser criterion or scree plot. Key parameters for water quality assessment are identified based on the primary groundwater quality parameters with high loadings on the selected PCs. These parameters capture essential aspects of water quality dynamics and form the minimum set of parameters for further analysis.

Multiple Linear Regression (MLR) analysis is conducted using a stepwise approach to establish relationships between the EWQI (dependent variable) and the selected physicochemical parameters (independent variables). The MLR model is iteratively developed, with parameters added or removed based on their significance and contribution to model fit. Model performance is evaluated using metrics such as coefficient significance, goodness of fit, and multicollinearity.

The established data reduction EWQI models are validated using a separate dataset of groundwater samples not used in model development. Model performance is assessed using metrics including coefficient of determination (R^2), Root Mean Square Error (RMSE), and Percentage Error (PE). The spring water quality in the current research is categorized into five grades based on the data reduction values of EWQI (Yang et al. 2023), including excellent quality (< 25), good quality (25–50), moderate quality (50–100), poor quality (100–150) and very poor quality (> 150).

Statistical software packages such as IBM SPSS are utilized for data analysis, including PCA, MLR modeling, and validation. Visualization tools like Origin and ArcGIS are employed for geospatial mapping, allowing for the visualization of spatial patterns of water quality parameters within the study area.

4.6. Identification of Recharge Area

Integration of the inputs coming from hydrological, geological, chemical and isotopic analysis of the study area for finding the possible recharge area of the spring.

Stage-I

- Surveyed springs were geotagged and geospatial database of the springs of Ravi River catchment were created which help in developing a better perspective of the study area in context of the genesis of the springs in the catchment.

Stage-II

- Spring locations were plotted on the base map viz. Digital Elevation Model of Ravi river basin.
- Geological map of the study area was prepared from existing literature and available online resources (e.g., BHUVAN).
- Geomorphological map of the study area was generated.
- Lineament map of the study area was prepared.

Stage-III

- First field visits were conducted during in the catchment for developing the physical understanding with the system.

- Field visits for detailed geological data collection were carried out

Stage-VII

- Recharge area of the springs were identified on the basis of geology, lithology, geomorphology, altitude, slope and aspect, meteorological conditions, land use and land cover, anthropogenic influence, in the region.
- Conceptual hydrogeological model were drawn for six springs.
- Plausible intervention for recharge were suggested.

Fig. 4.14 depicted the steps followed to identify the typology and possible recharge area of the selected vulnerable springs.

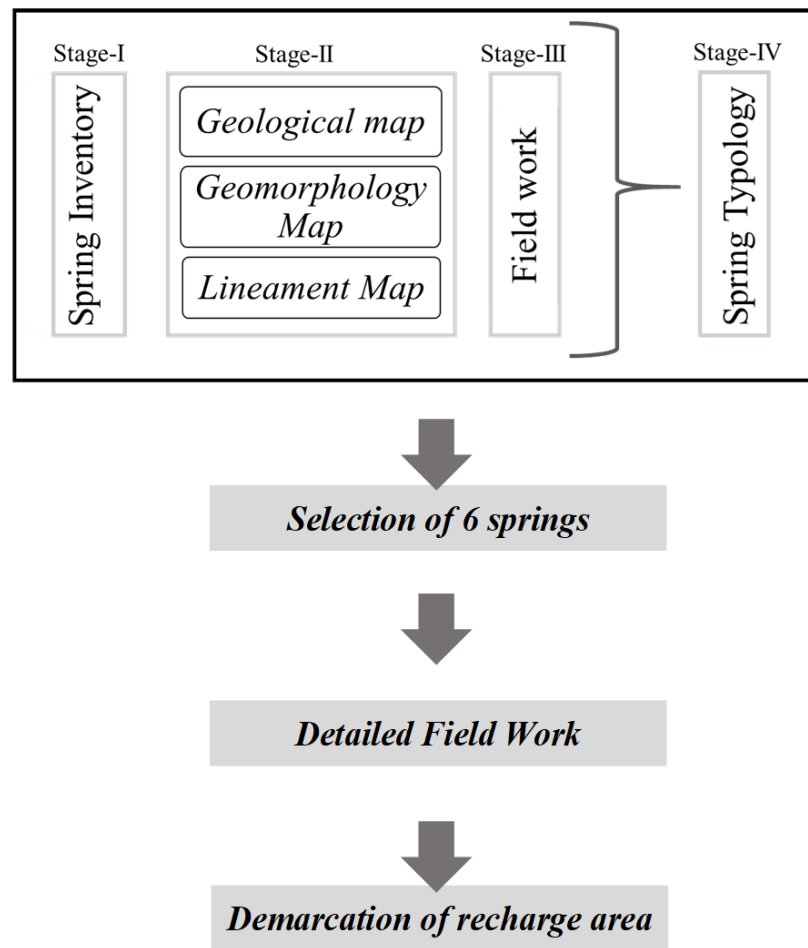


Fig. 4.14 Flow chart of the methodology adopted in the present study.

5. RESULTS AND DISCUSSIONS

5.1. Spring Characterization

An inventory of 981 springs is created after carrying out a detailed survey in Chamba district (one of the aspirational districts of Himachal Pradesh declared by NITI Aayog) falling under Ravi River catchment and given as Annexure-I. In phase-I of the PDS all springs were first geo-tagged using handheld GPS and subsequently information filled on a prescribed format using a sperate paper sheet. While in phase-2 of the PDS survey of the springs were entirely collected through mobile app developed in KoBo tool box. In phase first 424 springs were surveyed while 557 springs were surveyed in phase-2. As per survey only 15% springs (148 nos.) have private ownership while 85% springs are having the gram panchayat or community owenership. Besides, 12% springs are those which spring upstream area is under private ownership. In such springs it is difficult to implement springshed management programme without getting the confidence of the owners.

The information collected on various parameters were analyzed and discussed in the following text.

(a) Altitude wise spring genesis

Total 981 springs were surveyed in the catchment, out of 981 springs 23 springs are found to be sesaonal. Surveyed springs spread across the study area are located at 683 m *amsl* to 3248 m *amsl*. A distribution of springs vis-à-vis elevation zone is presented in Fig. 5.1. It can be seen that majority of the springs (681 out of 981) are to be found between 1000-2000 m, *amsl*. It shows that in this particular elevation zone geological and geomorphological condition are favorable for the formation of the springs. In high altitude areas slope is also very steep which discourage the formation of springs particularly depression type and it is manifested during the spring mapping where only 9 springs mapped above 2500 m, *amsl*.

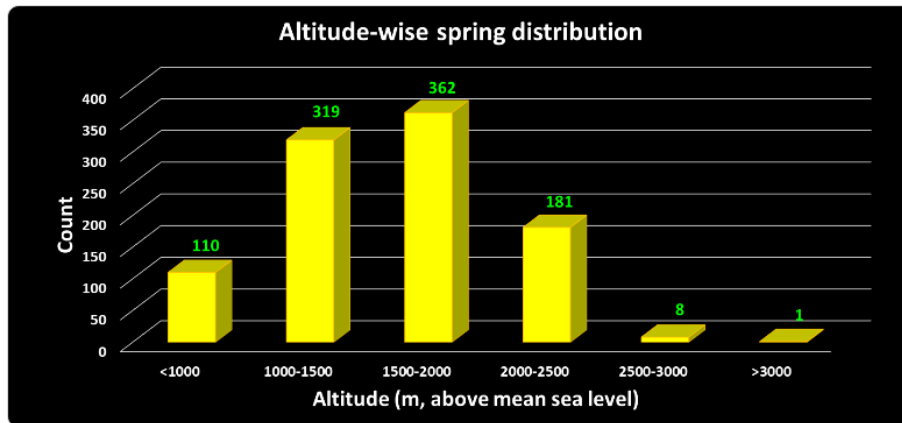


Fig. 5.1 Showing the distribution of springs in the Tawi catchment, Jammu and Kashmir, according to the discharge.

(b) Discharge wise classification of springs

During the study, discharge (in lpm) of 981 springs has been monitored and the data was further classified into 10 classes as <1 lpm to > 100 lpm discharge. The discharge of these springs varies from 0.1 to 300 lpm, with the highest no. of springs (n=231) discharging 2-5 lpm water. The details of the number of springs with respect to their discharge is given in Fig. 5.2. Further, the springs were classified on the basis of Meinzer's classification (Fig. 5.3). 48% of the springs fall in seventh category/class with a high discharge that vary from 10-100 lps. Further, 43.4% springs fall in sixth category with discharge varying from 0.1-1 lps and only 1.7% springs fall in fifth category with discharge of 1-10 lps. 3.2% springs were categorised as eight category and remaining 3.8 % of springs were categorized as seasonal.

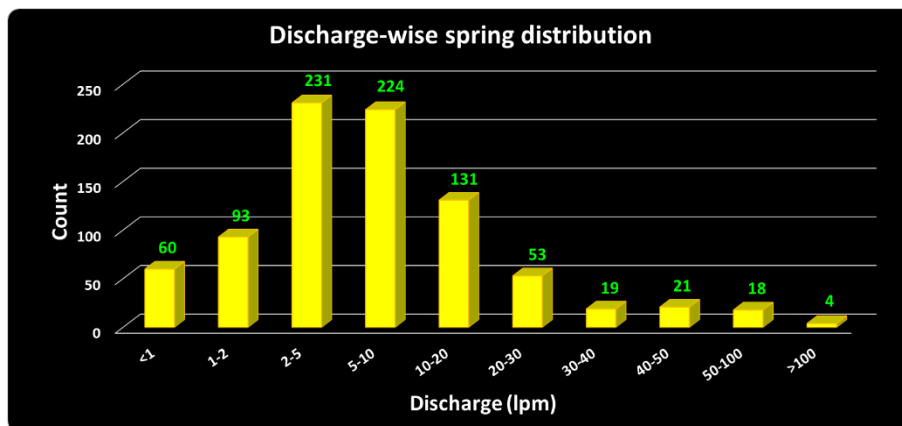


Fig. 5.2 Showing the distribution of springs in the Tawi catchment, Jammu and Kashmir, according to the discharge.

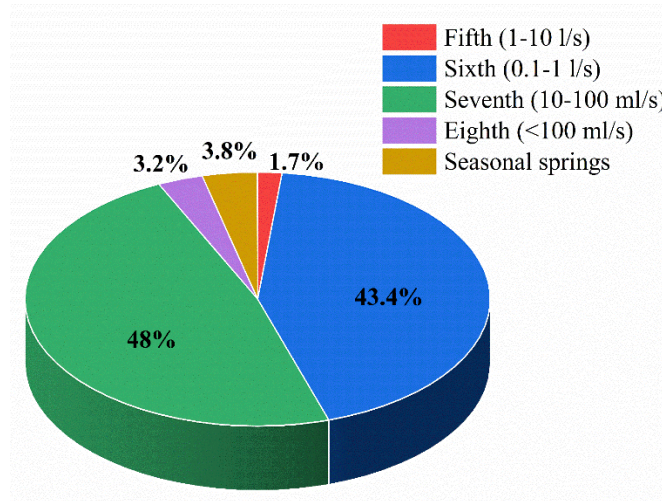


Fig. 5.3 Showing the Meinzer's classification of springs in Ravi catchment.

(c) Dependency on springs

People in the mountainous regions rely on the spring water to meet their daily requirements. The dependency level in most cases is determined by on the availability of sources as well as on requirement of the beneficiaries. In the present study, the dependency of no. of villages on springs was categorised into four classes (Fig. 5.4). Majority of the springs have low dependency level in context of dependent village. A total of 760 no. of total springs have dependency of only 01 villages each to fulfil their daily water requirement. Further, 147 no. of springs have dependency of 02 villages. 38 and 20 springs have 03 and 04 no. of villages dependent on each spring respectively.

Since, the locale population is dependent on the spring water at various levels, the dependency of population on each spring was also assessed during the study. Seven different classes have been identified based on population dependent on springs (Fig. 5.5). 156 number of springs constituting around 15.88 % have dependent population of < 50 people. A large number of populations with dependency of 100 to 150 people per spring reply on the 29.12% (286 nos.) of springs in the Ravi catchment. Further, only 15 no. of springs constituting 1.52% of total are being used by passer-by.

On the basis of these results, the data was further assessed and three different categories of dependency level i.e. High, medium and low were identified. Highest no. of springs i.e. 308 (31.36%) have high level of dependency. However, 295 nos. (30.0 %) and 355 nos. (36.15 %) springs have medium and low dependency levels respectively (Fig. 5.6).

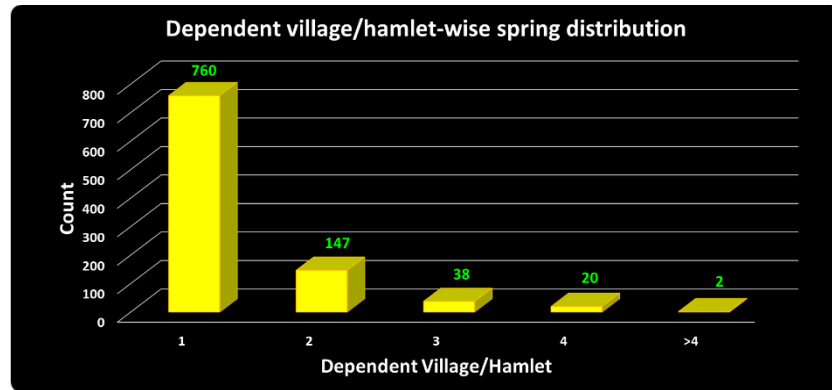


Fig. 5.4 Showing the dependency of villages on springs in the Ravi catchment.

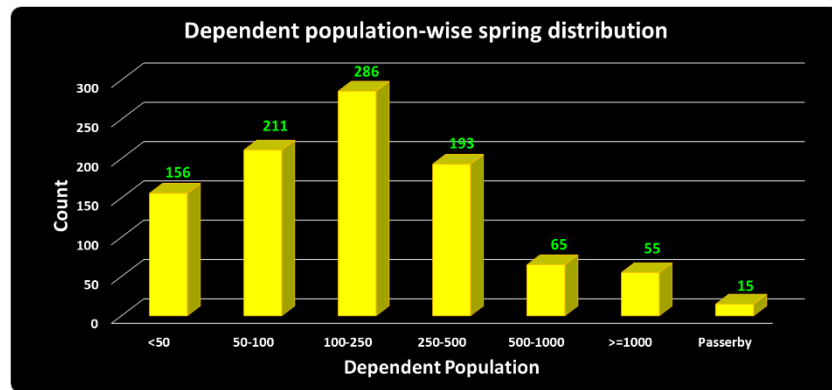


Fig. 5.5 Showing the dependency of population on springs in the Ravi catchment.

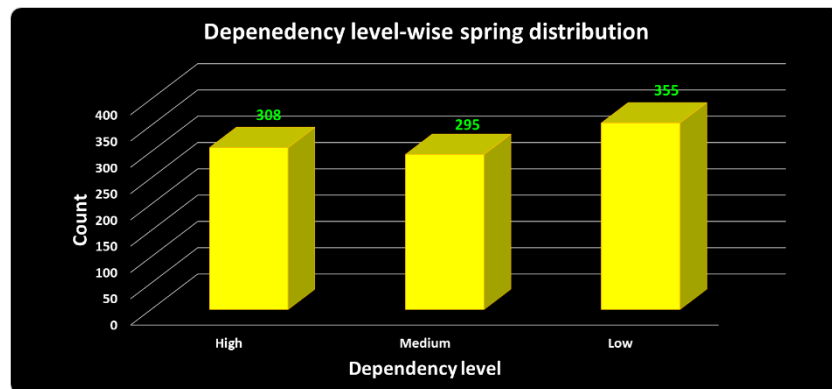


Fig. 5.6 Showing the dependency level of population on springs in the Ravi catchment.

(d) People's perception on spring discharge

During the field survey, the information related with the fluctuation of spring discharge over last decade was also gathered from locale population of the Ravi catchment. According to this information collected, discharge of 808 nos. constituting 82.28% of total springs has been decreased with time which may probably because of disruption or delay in the recharge zones due unplanned construction, lack of proper

vegetation cover leading to runoff of the precipitation etc. The increased discharge is observed only in 0.40% (4 nos.) of springs. However, the discharge of around 1.12% springs (11 nos.) has remain unchanged (Fig. 5.7).

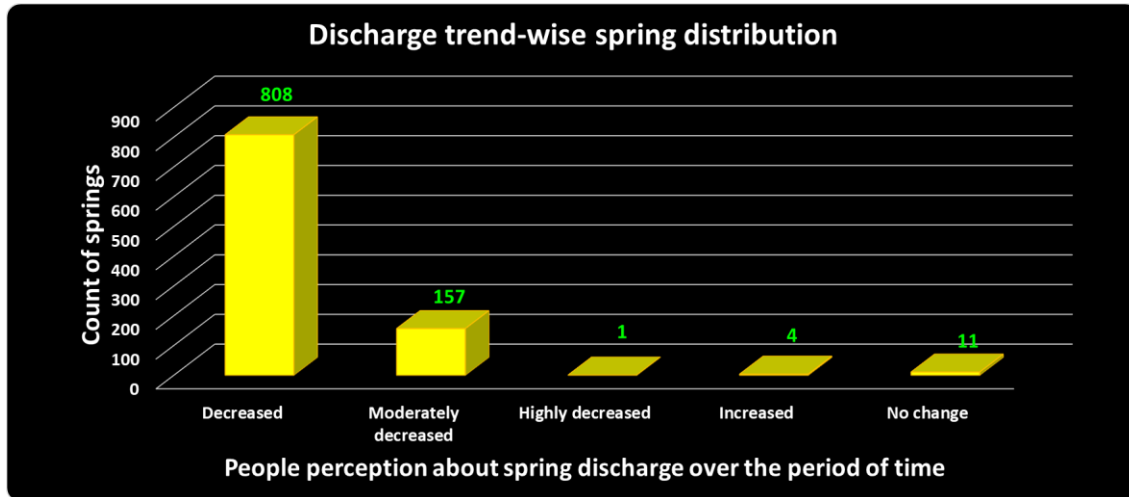


Fig. 5.7 Showing people’s perception of discharge of springs in the Ravi catchment. **(d)** Total Dissolved Solids (TDS mg/l)

Springs with an TDS < 50 mg/l account for 5% of the total sampled springs, with a total of 46 springs. Those with an TDS between 50 and 150 mg/l represent the largest proportion, constituting 37.8% of the total, with 350 springs falling within this range. Springs with an TDS between 150 and 250 mg/l account for 29.7% of the total, amounting to 275 springs. In the TDS range of 250 to 300 mg/l, there are 79 springs, making up 8.5% of the total. Springs with an TDS between 300 and 500 mg/l comprise the highest percentage, at 17.3%, with 160 springs falling within this range. Finally, springs with an TDS greater than 500 mg/l (not acceptable as per BIS drinking water norms) represent only 1.6% of the total, with total of 15 springs (Fig. 5.8).

(e) pH

Springs with a pH value below 6.5 constitute a minor portion, representing 18 springs. The majority of the sampled springs, accounting for 904 in total, have pH values ranging from 6.5 to 8.5, indicating a neutral to slightly alkaline nature. Only a small proportion of springs, with a total of 10, exhibit pH values exceeding 8.5 (Fig. 5.9).

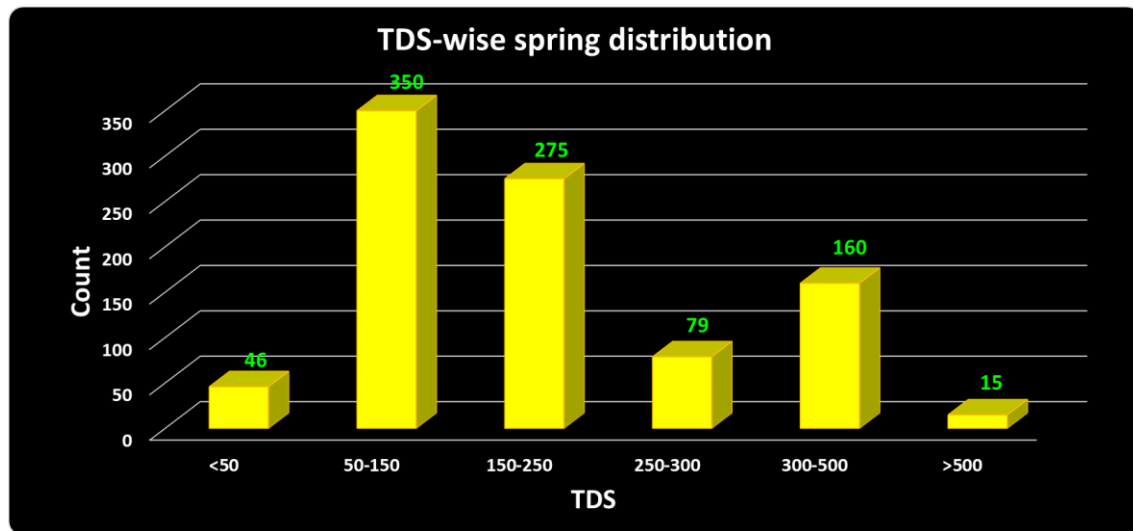


Fig. 5.8 Showing the categorization of springs on the basis of Total Dissolved Solids (TDS mg/l in the Ravi catchment.

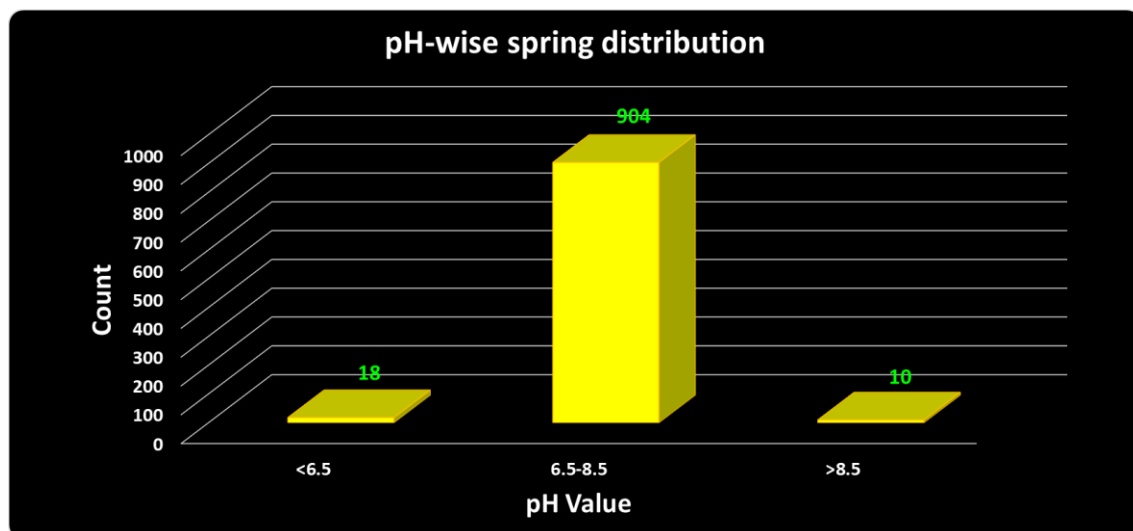


Fig. 5.9 Showing the categorization of springs on the basis of pH in the Ravi catchment.

(g) Land use at and upstream of springs

Most of the surveyed springs were to be found on forest land (59%) followed by pasture (16%) and agriculture land (13%) (Fig. 5.10a). However, landuse at upstream of the springs was to be found agriculture (43%) followed by forest (27%) and pasture (21%) (Fig. 5.10a). Since most of the springs in the catchment have possibilities of agriculture fields in their recharge zones, agriculture practices followed in the area will certainly have significant impact on springs' water quality and quantity as well. Most of the springs are located in the forest area, therefore role of forest department is very crucial in managing

the springs in the area. Hence it is recommended to take onboard forest department in all springshed management activities in the area.

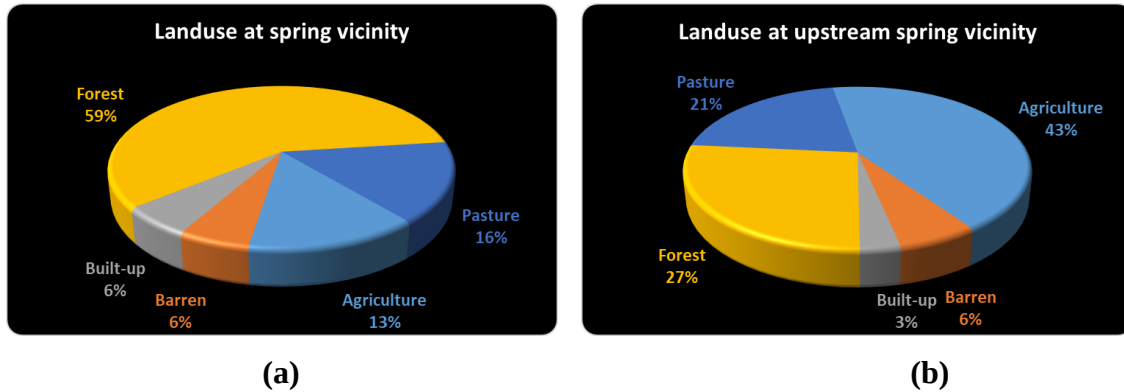


Fig. 5.10 Showing the landuse at (a) spring vicinity, and (b) upstream of spring vicinity.

Based on the collected information a “Spring Atlas of Ravi River catchment of Himachal Pradesh” (Fig. 5.11) was prepared and annexed as Annexure-II of the document

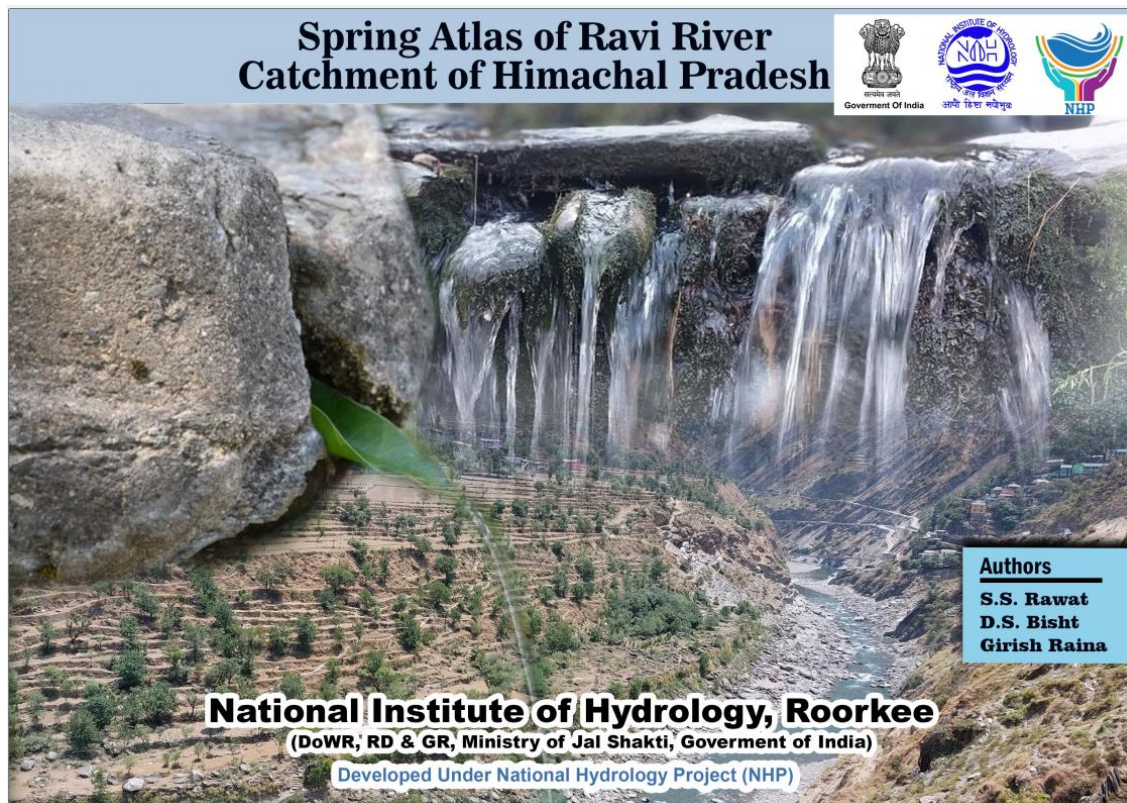


Fig. 5.11 Snapshot of the developed Spring Atlas of Ravi River Catchment of Himachal Pradesh (<http://117.252.14.250:8080/jspui/handle/123456789/7443>)

5.2. Vulnerability Index and Zonation

The interpretation of the data indicates that out of the total number of springs analyzed, 750 springs are classified as moderately vulnerable (MV), while 231 springs are classified as highly vulnerable (HV). This suggests that there are more springs with moderate vulnerability compared to those with high vulnerability. It's important to note that with a Vulnerability Index (VI) higher than 1 for all springs, none of them would fall into the "low vulnerability" category. Based on this information all springs indicates a certain level of vulnerability for each spring.

Generally, the VI values in the northwestern and southeastern part were substantially lower than those of the central, south, southwestern part (Fig. 5.12), indicating that springs in the central, south, southwestern part parts are more vulnerable. The distribution of low VI (1.03 to 1.67) springs shows widespread distribution and are mainly present at locations of Sabranjla, Charrah, Dhar, Saloni and Sundaja. On the contrary, the high VI (2.02 to 2.30) springs were concentrated in the central area of the Ravi River (including Chamba, Mehla, and Dharwala, Kharamukh). A major part of the study area contained springs of moderate VI (1.67-2.02) are majorly concentrated in regions of Dalhousie (Fig. 5.12). Estimated vulnerability Index of 981 springs are given in an Excel sheet as Annexure-III.

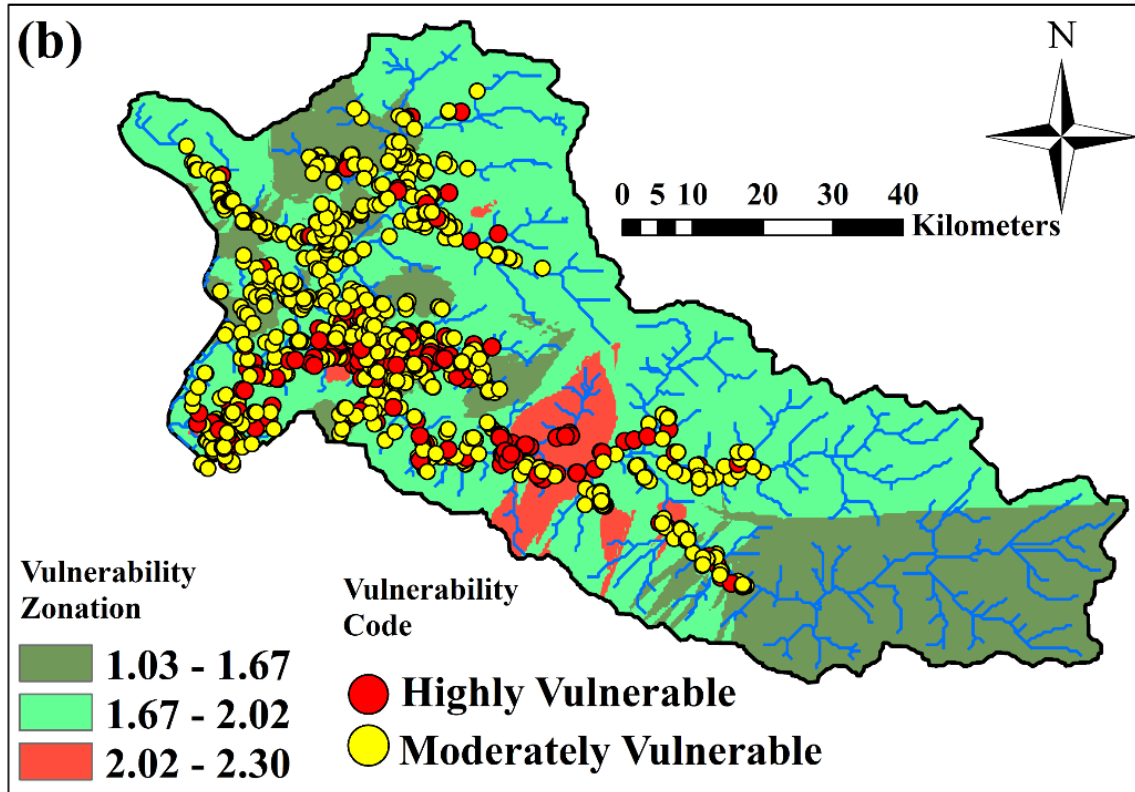


Fig. 5.12. Vulnerability Index and zonation mapping in the Ravi catchment.

5.3. Web-GIS based Information System of Himalayan Springs for Vulnerability Assessment and Rejuvenation (ISHVAR)

All the information collected during survey were converted into geospatial database. Different thematic layers will be generated using the database. The geo-tagged are made available in public domain through information system for download and visualize in Google Earth.

The ISHVAR provides consistent and authentic spring data along with user interactive features and functionalities in a ‘Single Window’ (<http://117.252.14.251:8080/TestSpring@Feb2020/>). It is a thin client scalable web enabled information system which provides facility to view these data in 2D. This is developed using open-source technologies i.e., Geoserver, HTML, and JavaScript. The system also makes available tools for better visualization and interpretation.

Home page:

This is used to visualize all the spatial layers such as Open Street Map, India Boundary, Study area boundary and spring locations (Fig. 5.13). The user will be provided with all layers in a tree structure format. They can turn on and off these layers based on

their area of interest/their specific requirement and can change its opacity. Various tools will be made available to explore these huge datasets. This also displays actual spatial and non-spatial processed data.

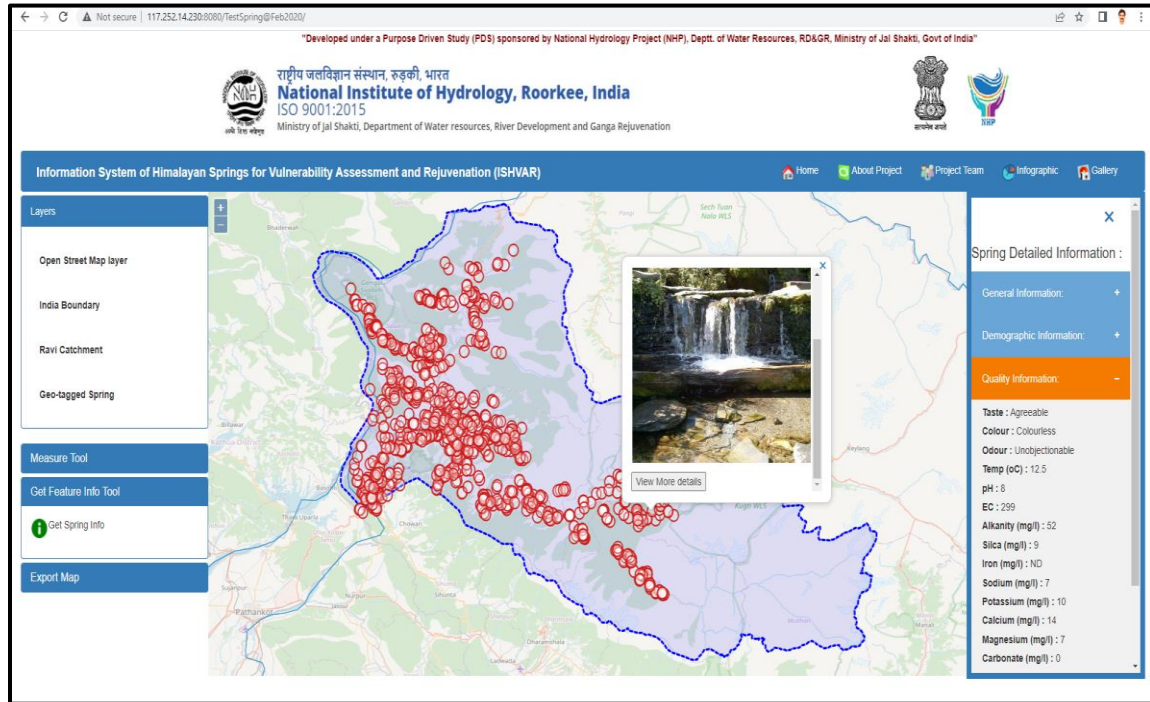


Fig. 5.13. ISHVAR Web-portal

The web portal utilizes the open street map in the backdrop which can be enabled/disabled from the option available under *Map Layer* section in the left side of the portal (Fig. 2). Similarly, other GIS boundaries viz. river basin's outline, springs' location can be turned on/ off. Various information tagged to specific springs can be accessed using the *Get Spring Info Tool* (Fig. 5.14). To view detailed info, user is required to select the *Get Spring Info Tool* and double click on the spring of interest. A dialogue box comprising various details along with the spring photograph at the time of survey will be opened upon clicking as shown in Fig. 5.15.

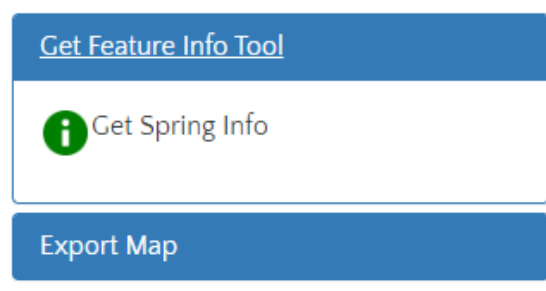


Fig. 5.14. Get Feature Info Tool

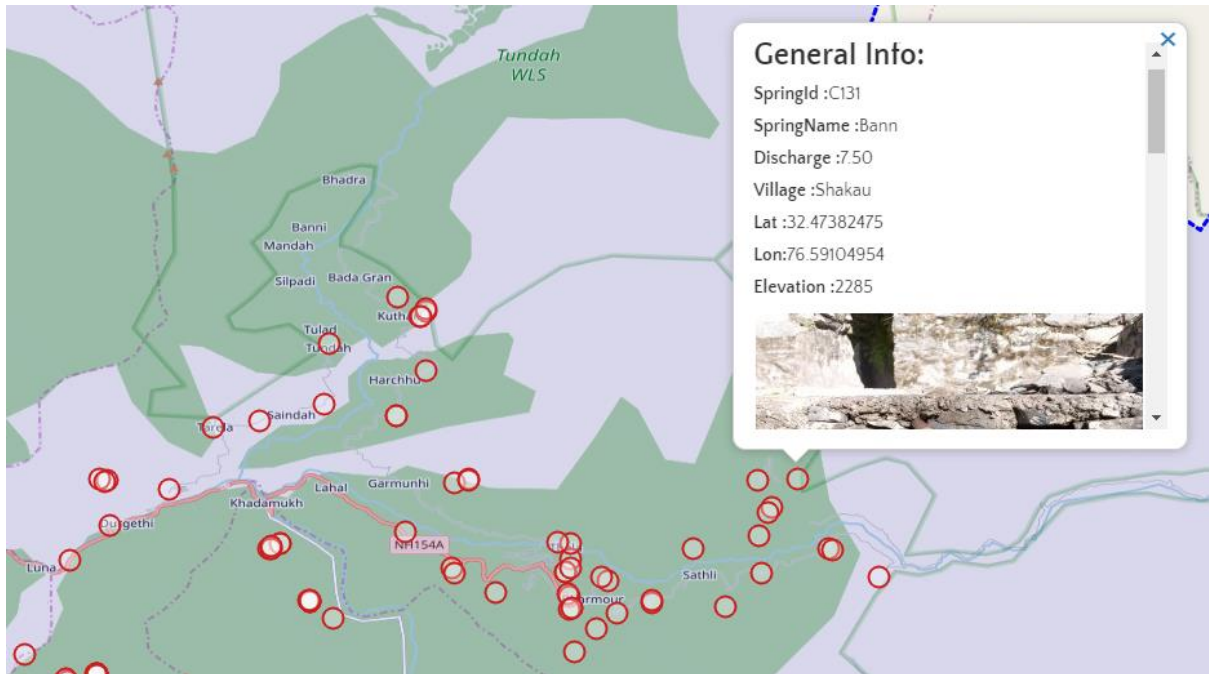


Fig. 5.15 Dialogue box showing spring information

On clicking of “View more details”, a side panel appears with collapsible accordion to visualize more details on “General Information”, “Demographic Information” and “Water quality information” (Fig. 5.16).

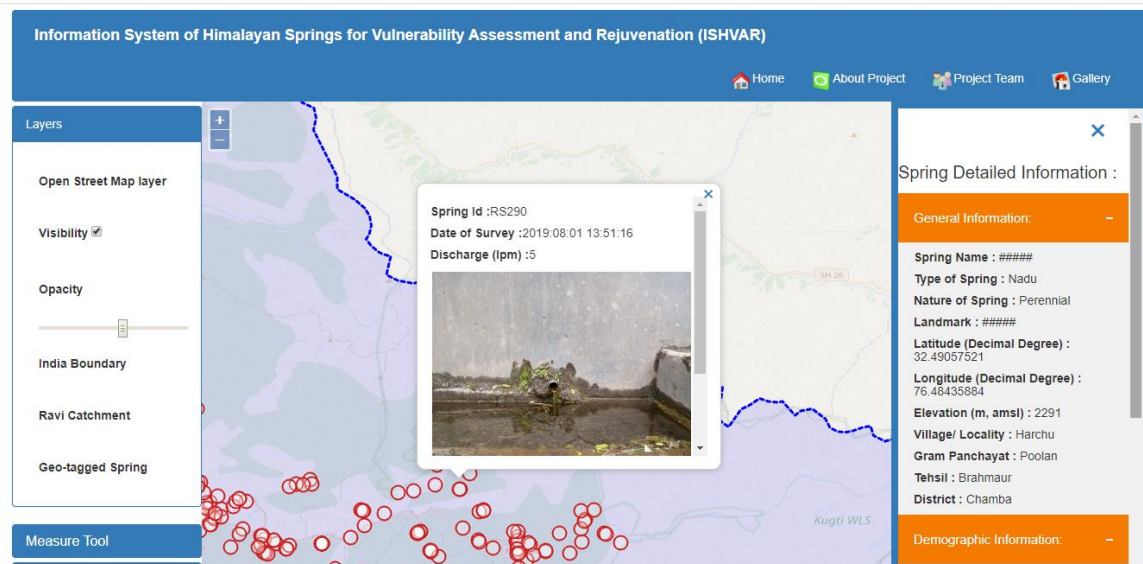


Fig. 5.16 Info pop-up and side panel box showing spring information

Web-portal also allows user to export the map in .pdf file using *Export Map* option (Fig. 5.17). The maps can be exported in 72 dpi (fast download), 150 dpi, and 300 dpi (slow download).

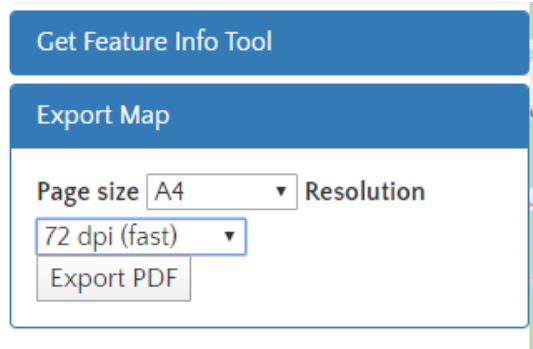


Fig. 5.17 Export Map tool

Other information regarding the project viz. data, project details, workforce and images of springs can be accessed from the tabs available on the menu bar (Fig. 5.18)



Fig. 5.18 Menu bar

About Project:

The About Project page of the system provides the information about the entire project, its objective, shows maps of study area and what methodology has been used to developed the database and also information about the work plan activity (Fig. 5.19).

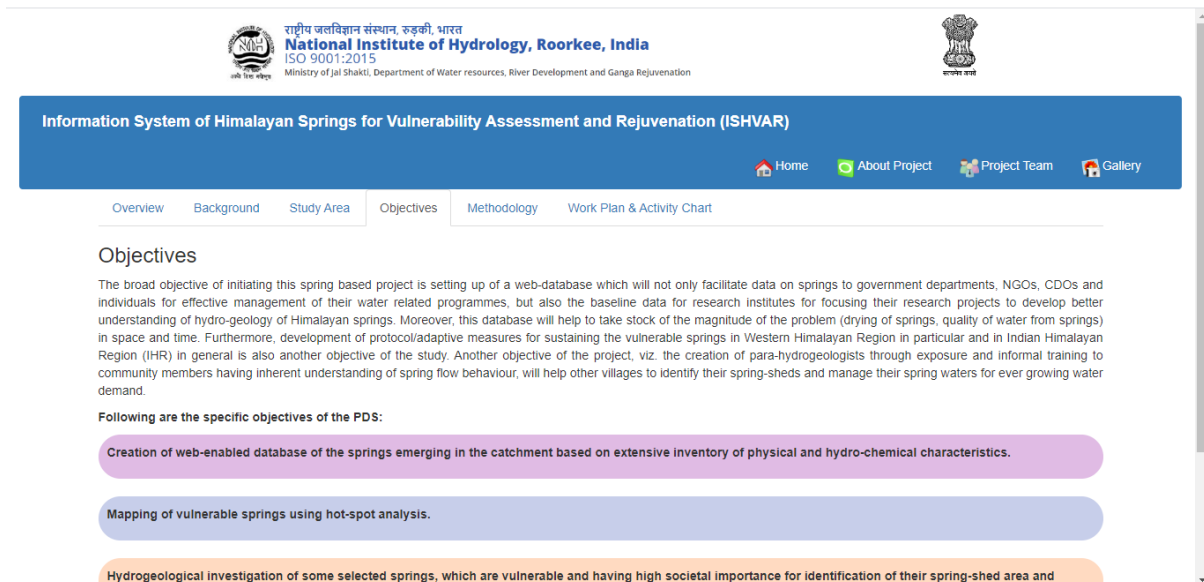


Fig. 5.19 About Project

Project Team:

This page provides information about the team involved in the formulation, data collection, development of such a comprehensive information system.

Infographic:

This section deals with the graphical representation of surveyed spring in terms of their discharge, elevation, dependent population, dependent village, level of dependency, people perception about spring discharge trend, land ownership at and upstream of spring, land cover type in the vicinity of spring, variation of pH and EC in Ravi River catchment (Fig. 5.20). Furthermore, this section also manifested the graphical representation of monthly rainfall data at seven rain gauge stations spread over the Ravi river catchment.

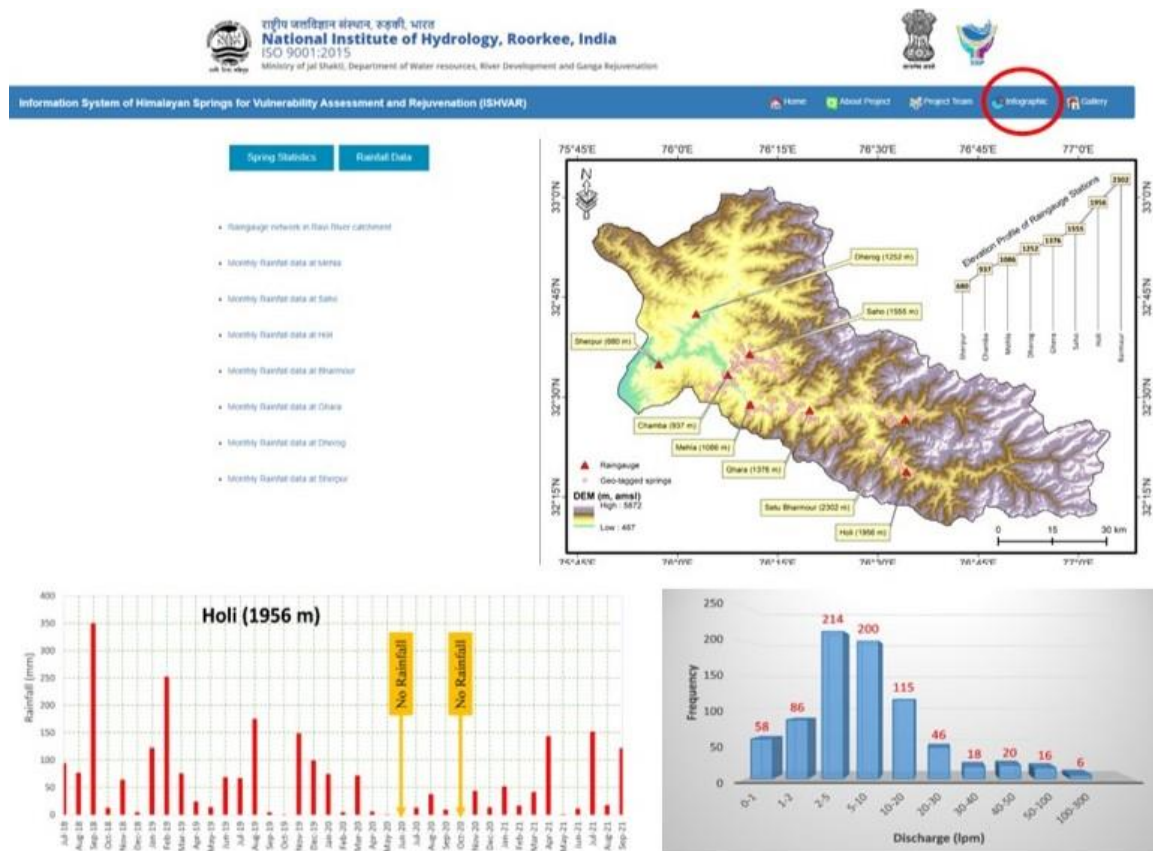


Fig: 5.20. Graphical representation of various characteristics of spring under “Infographic” tool

Gallery:

This page provides the photographs of various events and activities undertaken in this project. It shows the photographs of field investigation, Water quality testing, spring geotagging, springs, and knowledge dissemination by training and workshop (Fig. 5.20).



Fig: 5.21 Gallery

5.4. Hydrochemistry of Springs in Ravi River Catchment

The variation in the values of physical parameters (temperature, pH, EC and TDS) and major ions in the spring water is described below:

5.4.1 Physico-chemical parameters

pH Levels

The pH defines the amount of alkalinity or acidity of water and measures the concentration of hydrogen ions. The pH levels of the water samples ranged from 6.0 to 9.1, with an average of 7.5. Most of the sample values fall within the World Health Organization's (WHO) permissible range of 6.5 to 8.5 for safe drinking water. However, it's worth noting that 1.2% of the samples exceeded this recommended range, indicating potential deviations from optimal pH levels in some sources. These values suggest that the groundwater of the springs in Ravi catchment is neutral-to-slightly alkaline in nature, which is suitable for drinking purpose. Figure 3 provides a spatial distribution map of pH in the spring water.

Electrical Conductivity (EC)

The electrical conductivity (EC) of the water samples varied significantly, ranging from 10 to 1234, with an average of 266. While the majority of samples fell within acceptable limits, 0.3% exceeded the permissible limit set by the Bureau of Indian Standards (BIS). This suggests potential concerns regarding conductivity levels in a small subset of samples. Furthermore, EC is categorized as low enrichment of salts (Class-I) when EC is $< 1500 \mu\text{S/cm}$, medium enrichment of salts (Class- II) when EC varies from 1500 to $3000 \mu\text{S/cm}$, and high enrichment of salts (Class-III) when EC value $> 3000 \mu\text{S/cm}$ (Raheja et al., 2024). Accordingly, all the spring water samples fell under Class-I type, mainly due to rock-water interactions.

Temperature (T)

Temperature measurements ranged from 1.4 to 33°C , with an average of 16.7°C . It was found that all springs are cold water springs. However, these variations provide insights into the thermal characteristics of different water sources.

Total Dissolved Solids (TDS)

The total dissolved solids (TDS) in the water samples exhibited a wide range, from 46.2 to 787, with an average of 150. While all samples remained within acceptable BIS limit of 2000, suggesting generally satisfactory levels of dissolved solids in the majority of samples (Table 5.1). The TDS is divided into three different classes: freshwater, when TDS is $< 1000 \text{ mg/L}$; brackish water, when TDS value lies between 1000 and $10,000 \text{ mg/L}$; and saline water when TDS value is more than $10,000 \text{ mg/L}$ (Hynes 1983). All samples fall in freshwater category.

Table 5.1. Summary statistics of water quality parameters and comparison with WHO and BIS standards.

	Min	Max	Avg	SD	(WHO, 2017)	(BIS, 2012)	No. of samples exceeded the permissible limit	Percentage of samples exceeded the permissible limit
pH	6.0	9.1	7.5	0.5	6.5-8.5		14.0	1.94
EC	10	1234	266	215		3000	2.0	0.28
Temp	1.4	33.1	16.7	5.9				0.00
TDS	46.2	787	150	96	1000	2000	1.0	0.14
Alkalinity	1.0	5758	69	236		600	1.0	0.14
Na ⁺	1.1	99.7	19	21	200		0.0	0.00
K ⁺	0.5	72.1	8.1	10	12		166	23.0
Ca ²⁺	1.1	92.5	25	24	75	200	46	6.39
Mg ²⁺	1.3	57.5	9.7	8.2	30	100	22	3.06

HCO₃⁻	1.4	725	79	62		600	1.0	0.14
Cl⁻	0.7	40	9.5	6.9	250	1000	0.0	0.00
SO₄²⁻	1.0	244	21	23	250	400	0.0	0.00
NO₃⁻	0.1	18.0	1.5	1.5	45	45	2.0	0.28

5.4.2. Calcium (Ca²⁺) and Magnesium (Mg²⁺):

The concentration of calcium (Ca²⁺) and Magnesium (Mg²⁺) varied from 1.1 to 92.5 mg/L with a mean of 25.6 mg/L and 1.3 mg/L to 57.5 mg/L with a mean of 9.7 mg/L, respectively. Out of 720 samples, 46 (6.4%) spring water samples are found to have excess value than the recommended limits (BIS, 2012; WHO, 2017). Among all the cations (Ca²⁺, Mg²⁺, Na⁺, and K⁺) in water, Ca²⁺ is the dominant cation. Out of 720 samples, 22 (3.1%) spring water samples are found to have excess Mg²⁺ value than the recommended limits (BIS, 2012; WHO, 2017, Fig. 5.22).

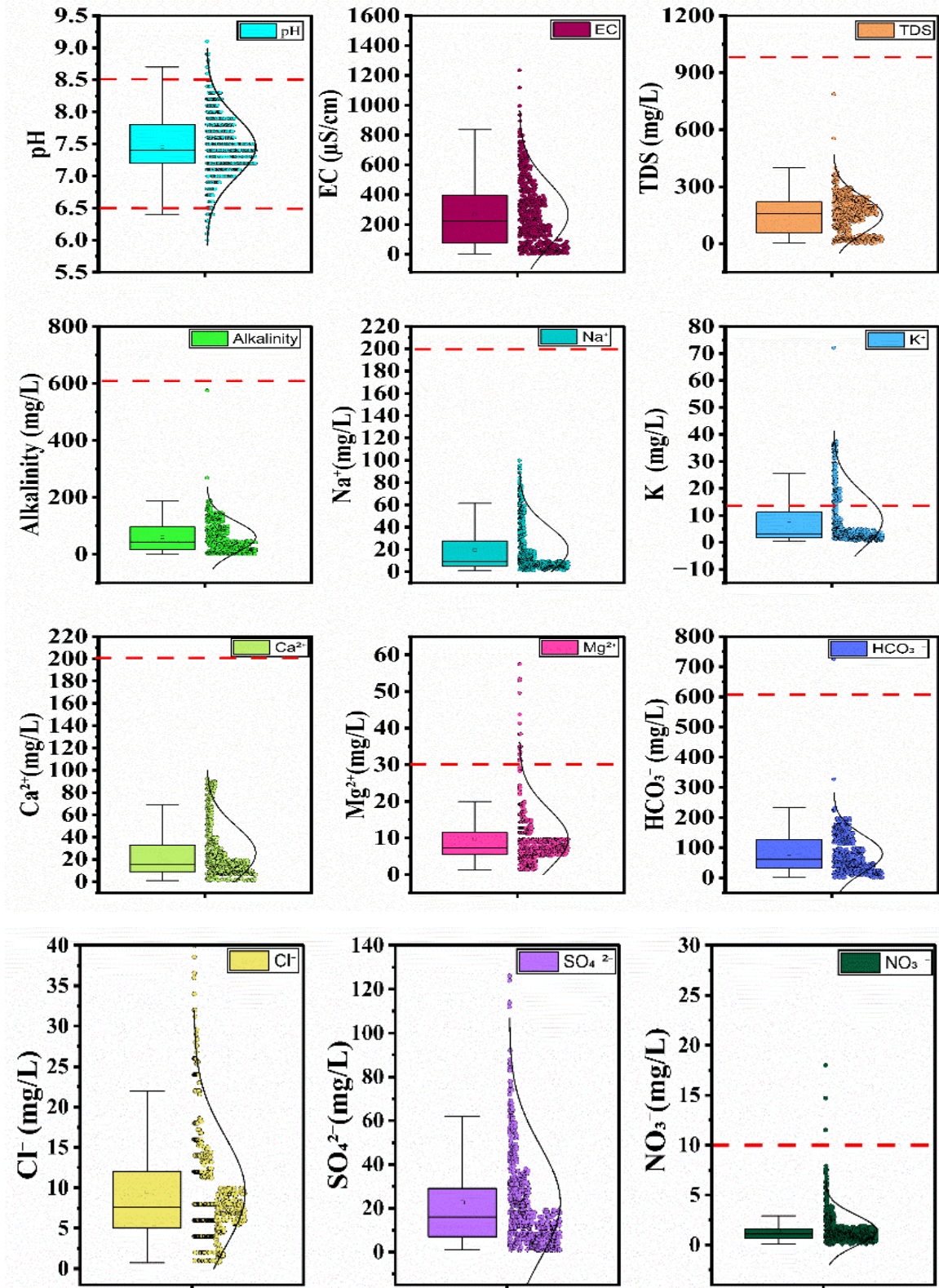


Fig. 5.22 Box-Whisker plots, distribution, and exceedance of each physicochemical parameter value compared to WHO Guidelines (2017) and BIS (2012).

5.4.3. Hydrochemical characteristics

The hydrochemical data was plotted on Piper diagram (Piper, 1944) (Fig.5.23) to identify the dominating hydrochemical facies in the study area. The Piper diagram (Fig. 6.2) shows that a majority of the samples are rich in alkaline earth, i.e., Ca^{2+} and Mg^{2+} and the weak acid (HCO_3^-) has exceeded the strong acid (SO_4^{2-}) (Fig. 5.23). The water is mainly of Ca-HCO_3 and Ca-Mg-HCO_3^- type (Fig. 5.23) with few samples having mixed or no dominant type of hydrochemical facies. Higher concentration of Ca^{2+} , Mg^{2+} and HCO_3^- in the study area indicates the dissolution of calcic minerals, carbonates and dolomites present in the study area.

Subsequently, the concentration of Na, Ca, Mg and HCO_3^- are used to distinguish the role of different weathering process viz. evaporite, silicates or carbonate dissolution (Gillardet et al., 1999). It is inferred that majority of the samples are clustered towards silicate weathering and carbonate dissolution zone (Fig. 5.24). A major part of Ravi catchment is covered by the rocks of sedimentary origin that includes sandstones, calcareous slate, shale, claystone and conglomerates which also confirms that the hydrochemical composition of groundwater is governed by dissolution of both, silicate and carbonate rocks.

The results infer a major role of silicate weathering and carbonate dissolution in the ion acquisition during the sampling period. This is evident through the binary plots in

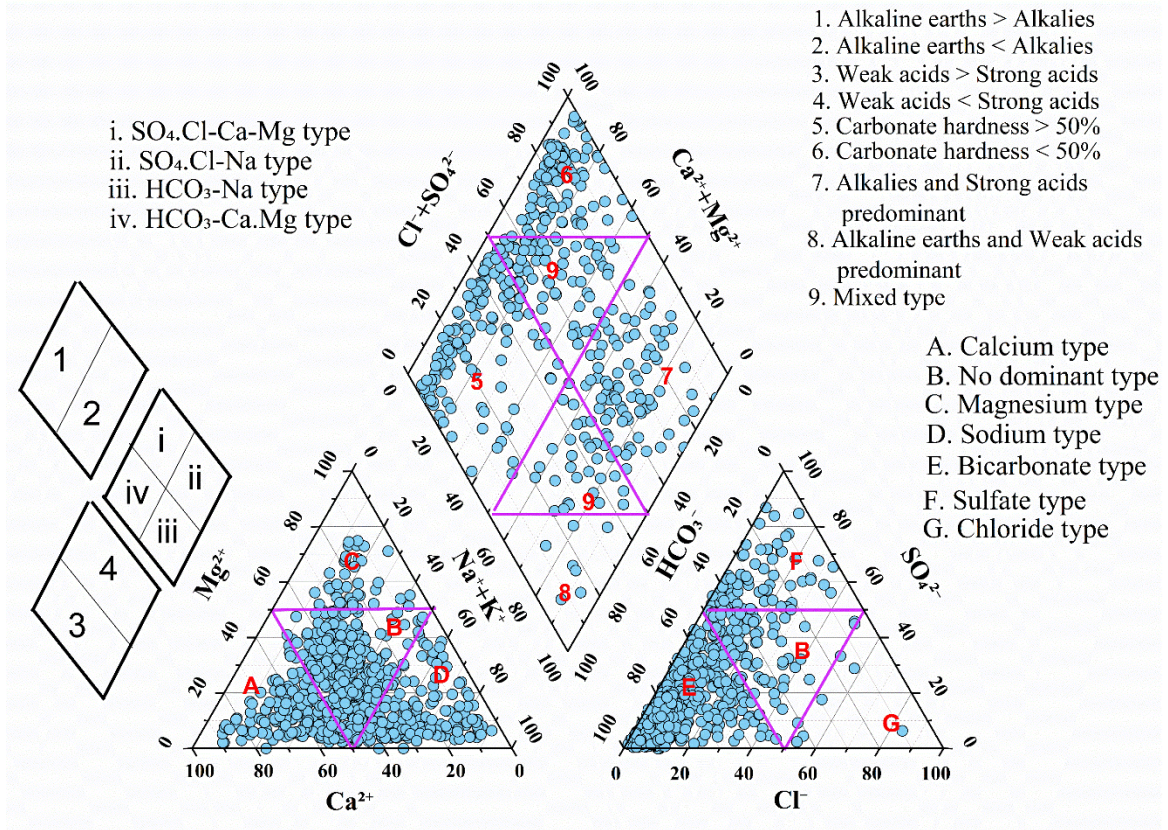


Fig. 5.23. Piper diagram showing hydrochemical facies of spring water in Ravi catchment, Jammu, India.

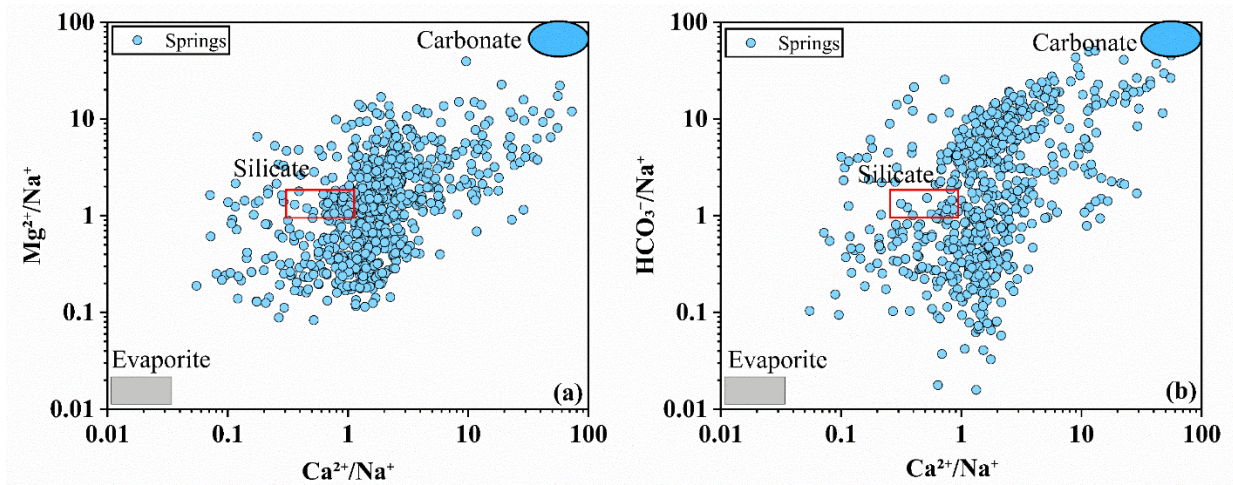


Fig. 5.24. Molar ratios of Ca/Na vs. Mg/Na, and HCO_3/Na in the springs. Endmember compositions of carbonate and evaporite are assigned from Gaillardet et al. (1999), and molar ratios of silicates were assigned from Dar et al., 2023.

which majority of the samples are clustered towards silicate weathering and carbonate dissolution zones (Fig. 5.24).

With the help of 719 surveyed spring's water quality data (point data), spatial maps for different water quality parameters (pH, EC, Temperature, TDS, Na^+ , K, Ca^{2+} , Mg^{2+} , HCO_3^{2-} , Cl^- , SO_4^{2-} , NO_3^{2-}) of Ravi River catchment were created and given in Fig. 5.25. For interpolation of point data IDW (Inverse Distance Weighting) technique in the ArcGIS environment was used. Inverse Distance Weighting (IDW) interpolation is a spatial interpolation technique used to estimate values for locations within a study area based on the values of surrounding known data points. It assumes that values at unknown locations can be estimated by giving more weight to nearby known data points and less weight to those farther away.

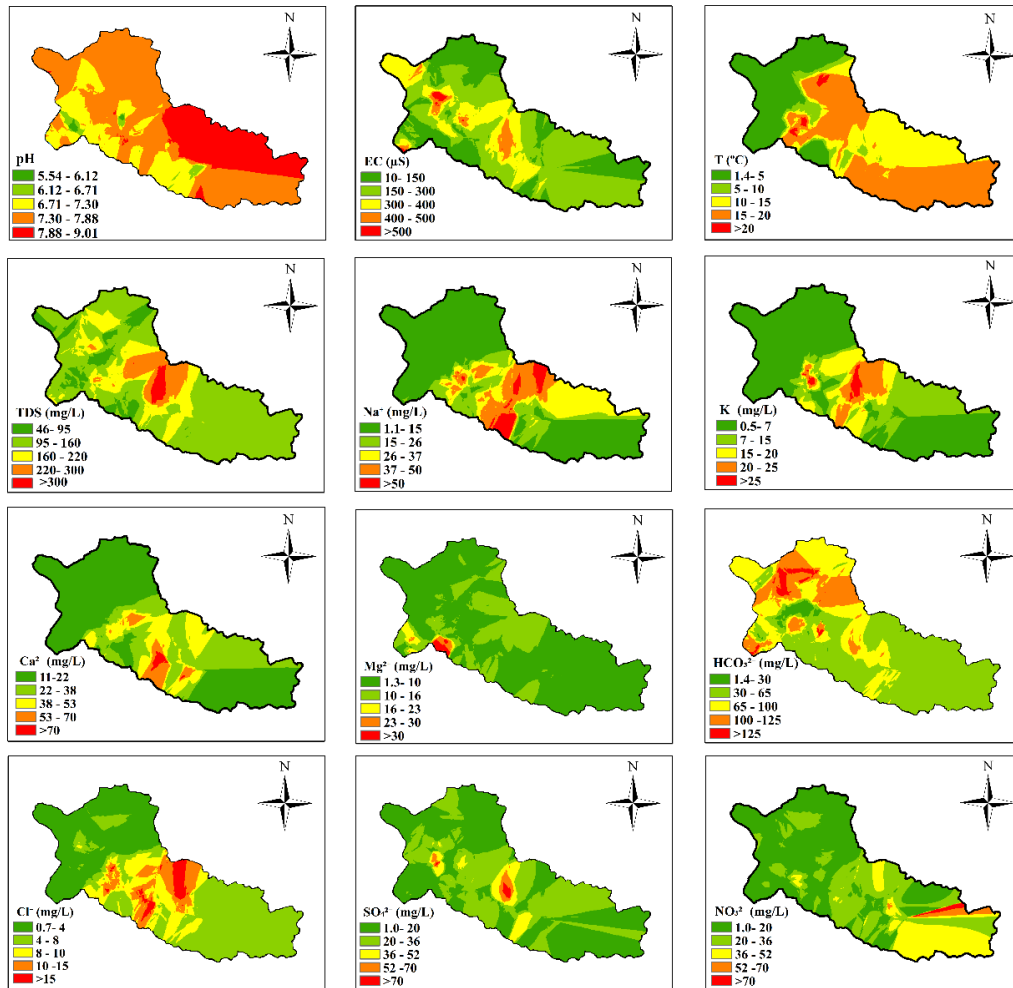


Fig. 5.25 Spatial variability maps pertaining to various parameters of groundwater in Ravi River catchment based on the spring's water quality point data.

These types of spatial maps have immense useful to understand the groundwater quality and its spatial verifiability in the catchment. This will help to the local stakeholders to find out the suitable zones from where adequate quality potable water can be tapped. Furthermore, in mountains there is sparse network of piezometer to monitor the groundwater quality and quantity, in such situation springs may be act as natural piezometer for periodical observations of groundwater quality.

5.4.3.1. *Inferences*

- a) The hydrochemical composition of the Ravi catchment is derived from the dissolution of carbonate and silicate rocks.
- b) The primary hydrochemical facies are Ca-HCO_3 and Ca-Mg-HCO_3^- type.
- c) The abundance of HCO_3^- in the water range between silicate and carbonate dissolution, however, cations are mainly derived from silicate weathering.
- d) In the overall samples collected during the study period, the water is of mildly acidic to alkaline in nature.
- e) High concentration of K^+ and Na^+ is due to dissolution of sodic-rich minerals like plagioclase/clinopyroxene.

5.4.4. Sources of Ions in spring water

Research conducted previously has underscored the significance of assessing the proportion of major ions present in water as a valuable approach for identifying potential water-rock interactions. If the concentrations of Na^+ and Cl^- arise from salt dissolution, the molar ratio of Na^+/Cl^- will be 1 (Fig. 5.26a). This study observed that spring water samples in the study area are not evenly distributed around the $y = x$ line, indicating that Na^+ and Cl^- concentrations do not primarily originate from salt dissolution. Furthermore, mostly the samples exhibited higher Na^+ concentrations, possibly due to cation exchange during spring water flow, where spring water interacts with silicate minerals. In Fig. 5.26b, it was observed that the impact of gypsum dissolution is minimal in the study region as the concentrations of Ca^{2+} is much higher than the SO_4^{2-} in spring water samples. Despite the presence of gypsum layers in the Ravi catchment, the $\text{SO}_4^{2-}/\text{Ca}^{2+}$ ratio in water samples was mainly less than 1, implying that Ca^{2+} presence is not due to gypsum dissolution but result from the dissolution of other carbonate minerals like calcite and dolomite (Fig.5.24). The $\text{Ca}^{2+}/\text{HCO}_3^-$ ratios for dolomite and calcite dissolution are 1:1 and 1:2, respectively. Most samples in the study area were positioned below the calcite dissolution line ($y = x$

contour), indicating the presence of predominant calcite dissolution as compared to dolomite dissolution. However, the samples between the $y = x$ and $y = 2x$ lines in Fig. 5.26c, indicate the presence of both dolomite and calcite dissolution. Results indicate that the $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratio often used to distinguish carbonate and silicate mineral dissolution sources showed values greater than 1 in most spring water samples, suggesting influences from both carbonate and silicate mineral dissolution. The ratio in Fig. 5.26e indicated that the primary source of ions in spring water was from the dissolution of calcite and silicate minerals, as shown by the proximity of spring water samples to the $y = x$ line in the $(\text{Ca}^{2+} + \text{Mg}^{2+})$ and $(\text{HCO}_3^- + \text{SO}_4^{2-})$ binary diagram.

Ion exchange reactions between water and aquifer matrix, commonly assessed by examining the relationship between Na^+ , K^+ , and Cl^- concentrations versus Ca^{2+} , Mg^{2+} , HCO_3^- , and SO_4^{2-} , showed that most spring water samples exhibited negative CAI-I values (Fig. 5.26f), indicating forward cation exchange reactions, with Ca^{2+} and Mg^{2+} ions in the spring water replaced by K^+ and Na^+ ions in the aquifer.

5.4.5. Establishment of the data reduction EWQI Models for springs of Ravi catchment

The Table 5.2 presents the factor loadings of selected variables, eigenvalues, and the percentage of total variance explained by the main components of spring water in the Ravi catchment. Principal Component Analysis (PCA) was conducted to identify the underlying patterns in the dataset and to reduce its dimensionality while retaining the most significant information. PC1 has high loadings for parameters such as TDS, alkalinity, and HCO_3^- , indicating that it represents aspects related to water mineralization and alkalinity. These parameters likely contribute significantly to variations observed in the dataset along PC1. PC1 has high loadings for parameters such as TDS, alkalinity, and HCO_3^- , indicating that it represents aspects related to water mineralization and alkalinity. These parameters likely contribute significantly to variations observed in the dataset along PC1. PC2 include Na^+ , K^+ , and Cl^- , suggesting that PC2 may capture variations associated with the presence of major ions in the water, such as sodium, potassium, and chloride. PC3 shows high loadings for parameters like T and Mg^{2+} , indicating that PC3 likely reflects variations related to water temperature and magnesium concentrations. Parameters such as Cl^- , SO_4^{2-} , and Ca^{2+} exhibit significant loadings on PC4, suggesting that this component may represent variations associated with the presence of these ions in the water. The main contributors to

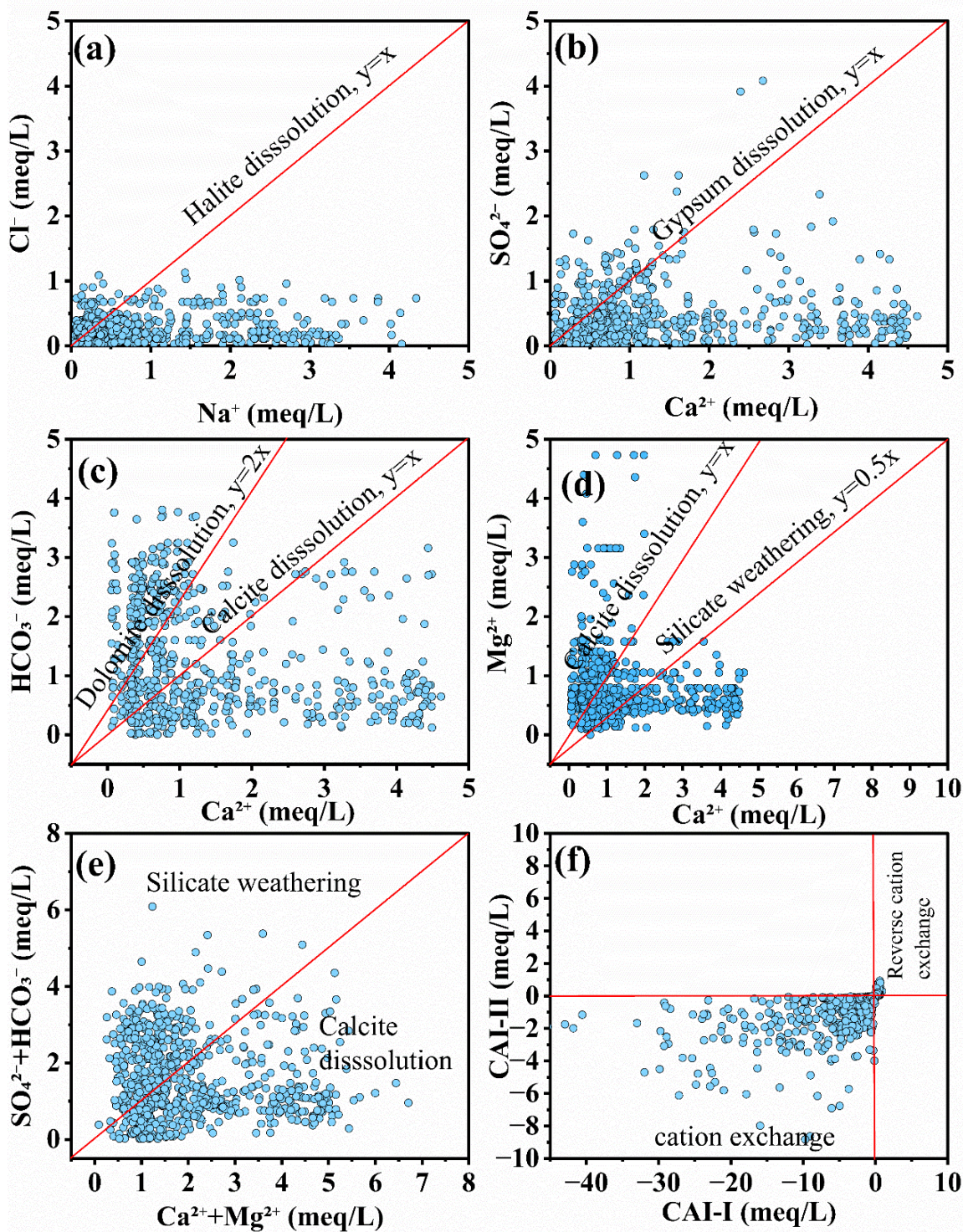


Fig. 5.26 Scatter plots of (a) Cl^- vs. Na^+ ; (b) SO_4^{2-} vs. Ca^{2+} ; (c) HCO_3^- vs. Ca^{2+} ; (d) HCO_3^- vs. Mg^{2+} ; (e) $(\text{HCO}_3^- + \text{SO}_4^{2-})$ vs. $(\text{Ca}^{2+} + \text{Mg}^{2+})$; (f) Chloro alkaline indices CAI-I vs. CAI-II.

PC5 include EC, and SO_4^{2-} , indicating that PC5 may capture variations related to these parameters. Parameters such as NO_3^- and pH show notable loadings on PC6, suggesting that this component may represent variations associated with nitrate concentrations and pH levels. The cumulative percentages of variance explain how much total variability is accounted for by each successive principal component. For example, PC1 and PC2 together explain 39.1% of the total variance.

The results suggest that the spring water quality parameters in the Ravi catchment exhibit complex patterns of variability, with different principal components capturing distinct aspects of water quality. PC1 appears to represent overall mineralization and alkalinity, while subsequent components capture variations related to specific ions, temperature, and other water quality characteristics. These findings can help identify underlying patterns in water quality data, prioritize parameters for monitoring and management, and understand the factors influencing spring water quality in the Ravi catchment.

Table. 5.2 Factor loadings of selected variables, eigenvalues and percentage of total variance explained by the main components of spring water in Ravi catchment.

	PC1	PC2	PC3	PC4	PC5	PC6
pH	0.05	0.10	-0.45	0.51	-0.19	0.26
EC	0.19	0.29	-0.41	-0.29	0.22	-0.11
T	0.01	0.02	0.42	-0.19	0.56	-0.01
TDS	0.56	0.00	0.10	0.01	-0.03	0.04
Alkalinity	0.56	-0.06	0.08	0.04	-0.02	0.03
Na⁺	-0.02	0.49	0.25	-0.04	-0.23	-0.07
K⁺	-0.001	0.53	0.14	0.19	0.18	0.29
Ca²⁺	-0.003	0.32	0.16	-0.44	-0.42	-0.10
Mg²⁺	-0.09	-0.34	0.37	0.20	0.09	0.17
HCO₃⁻	0.56	-0.06	0.08	0.04	-0.02	0.03
Cl⁻	-0.02	0.39	0.15	0.40	0.28	0.08
SO₄²⁻	0.00	0.01	-0.38	-0.36	0.42	0.35
NO₃⁻	0.04	0.06	-0.14	0.25	0.26	-0.82
Eigenvalue	3.1	2.0	1.5	1.3	1.3	1.0
Percentage of Variance (%)	23.7	15.4	11.5	10.0	9.7	7.7
Cumulative (%)	23.7	39.1	50.6	60.6	70.3	78.1

Table 5.3 presents the results of the MLR analysis for the EWQI (MRA) models, showcasing the R^2 values, adjusted R-squared (Adj.R²) values, Root Mean Square Error

(RMSE), and p-values for each model. Starting with Model 1, which includes only TDS as a parameter, the R^2 value is 0.11, indicating a relatively weak correlation with the dependent variable. As additional parameters are added, such as Na^+ , Ca^{2+} , and Alk in Models 2, 3, and 4, respectively, the R^2 values gradually increase, suggesting improved model performance. Notably, Model 5, which incorporates K^+ as a parameter, exhibits a substantially higher R^2 value of 0.79, indicating a strong correlation between the selected parameters and the EWQI. As more parameters are added in subsequent models, such as Model 6, which includes TDS and K^+ , and Model 7, which incorporates Alk, K^+ , Na^+ , Cl^- , and SO_4^{2-} , the R^2 values continue to increase, reaching a peak of 0.94 in Models 11 and 12. These models, which include multiple parameters such as TDS, Alk, K^+ , Na^+ , Cl^- , SO_4^{2-} , and NO_3^- , demonstrate a robust correlation with the EWQI. Additionally, all models exhibit statistically significant results with p-values < 0.001 , indicating that the selected parameters have a significant impact on the EWQI. Overall, the analysis highlights the effectiveness of incorporating multiple parameters in the EWQI (MRA) models to enhance the assessment of groundwater quality.

Table 5.3 presents the outcomes of a MLR analysis aimed at identifying the primary spring water quality parameters influencing the EWQI in the Ravi catchment. The table shows various models, each incorporating different combinations of spring water parameters, along with corresponding statistical metrics. Initially, TDS don't emerge as the controlling factor, with an insignificant R^2 value of 0.11, indicating that it accounts only 11% of the variance in the EWQI. Subsequent inclusion of parameters such as Na^+ , Ca^{2+} , and Alkalinity substantially improved model performance, as evidenced by increasing R^2 values. However, these are insignificant. The Inclusion of K^+ increases model statistics significantly indicating K^+ as a dominant factor controlling the EWQI. Models incorporating combinations of TDS+Alk+ K^+ + Na^+ (Model 9) parameters demonstrated high R^2 values exceeding 0.90, indicating robust explanatory power. Additionally, low p-values (< 0.001) underscore the statistical significance of the relationships between the selected parameters and the EWQI. Moreover, the RMSE values reflect the accuracy of model predictions, with lower values indicative of better predictive performance. In summary, the results highlight the pivotal role of TDS, Alk, K^+ , and Na^+ as key indicators for assessing spring water quality in the Ravi catchment using the EWQI–MLR approach.

Upon analyzing the performance metrics of the EWQI (MRA) models, it was observed that Model 4, consisting of TDS and Alkalinity (Alk), displayed a relatively higher R^2 value of 0.55 and a lower RMSE of 6.39 compared to the other single-parameter models. However, upon incorporating additional parameters, such as K^+ (Model 5), the R^2 value significantly increased to 0.79, while the RMSE decreased to 4.29. Subsequently, the inclusion of Alk and K^+ (Model 8) resulted in a further enhancement of the R^2 value to 0.90 and a decrease in RMSE to 2.96. Notably, Model 9, which included TDS, Alk, K^+ , and Na^+ , exhibited a substantially higher R^2 value of 0.93 and a lower RMSE of 2.50 compared to the previous models. The subsequent addition of Cl^- , SO_4^{2-} , and NO_3^- (Models 10 to 12) did not lead to significant improvements in R^2 values but further reduced the RMSE. Ultimately, Model 9, comprising TDS, Alk, K^+ , and Na^+ , demonstrated the highest R^2 value of 0.93 and lower RMSE of 2.50 among all models, indicating its superior performance in predicting spring water quality. These findings suggest that the inclusion of TDS, Alk, K^+ , and Na^+ as key parameters in the EWQI (MRA) model yields the most accurate assessment of spring water quality in this study.

Table 5.3 Key parameter selection of the EWQI (MRA) models from the multiple linear regression (MLR) model based on the training data.

Parameter selection	EWQI (MRA)				
	Models	R^2	Adj. R^2	RMSE	<i>p-value</i>
TDS	Model 1	0.11	0.11	8.92	>0.001
TDS+ Na^+	Model 2	0.24	0.24	8.25	>0.001
TDS+ Ca^{2+}	Model 3	0.25	0.25	8.19	>0.001
TDS+Alk	Model 4	0.55	0.54	6.39	>0.001
K^+	Model 5	0.79	0.79	4.29	<0.001
TDS+ K^+	Model 6	0.88	0.88	3.34	<0.001
Alk+ K^+ + Na^+ + Cl^- + SO_4^{2-}	Model 7	0.87	0.87	3.40	<0.001
TDS+Alk+ K^+	Model 8	0.90	0.90	2.96	<0.001
*TDS+Alk+K^++Na^+	Model 9	0.93	0.93	2.50	<0.001
TDS+Alk+ K^+ + Na^+ + Cl^-	Model 10	0.93	0.93	2.50	<0.001
TDS+Alk+ K^+ + Na^+ + Cl^- + SO_4^{2-}	Model 11	0.94	0.93	2.43	<0.001
TDS+Alk+ K^+ + Na^+ + Cl^- + SO_4^{2-} + NO_3^-	Model 12	0.94	0.93	2.43	<0.001

*Note: The Model 9 represents the min number of parameters retained to calculate the EWQI (MRA).

The PCA model for the EWQI exhibited a high coefficient of determination (R^2) of 0.94, indicating a strong correlation with the EWQI model (Fig. 5.27). Additionally, the percentage of error (PE) associated with the PCA model was 4.19%. This suggests that the PCA model performed well in predicting the EWQI, with a relatively low margin of error. On the other hand, the MLR model for the EWQI showed a slightly lower R^2 value of 0.92 compared to the PCA model. However, the MLR model demonstrated a lower percentage of error, with a PE of 1.12% (Fig. 5.27). Despite the slightly lower R^2 value, the MLR model displayed higher accuracy in predicting the EWQI with a reduced margin of error.

These findings indicate that while both the PCA and MLR models are effective in assessing groundwater quality using the EWQI, the MLR model outperforms the PCA model in terms of prediction accuracy. The lower percentage of error associated with the MLR model suggests that it provides a more reliable and efficient method for evaluating groundwater quality in this study.

5.4.6. Water Quality Assessment Using the EWQI, EWQI (PCA), and EWQI (MRA) models

Table 5.4 presents the results of water quality assessment utilizing three distinct models: EWQI, EWQI (PCA), and EWQI (MRA), categorized by spring water types and corresponding EWQI ranges. Each category denotes the count and percentage of samples falling within specified EWQI score intervals for each model. In the "Excellent" category ($EWQI < 25$), the EWQI model identified 525 samples, while the PCA and MRA models detecting 544 and 525 samples, respectively. The PCA model exhibited the highest proportion of samples in this category (75.7%), followed by the EWQI (MRA) model (73.2%) and the EWQI model (73.0%). In the "Good" category ($EWQI 25-50$), the EWQI model detected 185 samples, while the PCA and MRA models identified 117 and 84 samples, respectively. Within this range, the EWQI model demonstrated the highest percentage of samples (25.7%), followed by the EWQI (PCA) model (16.3%) and the EWQI (MRA) (11.77%). Conversely, the "Moderate" category ($EWQI 50-100$) contained 8, 57 and 110 samples according to all three models. The percentage of samples within this range varied from 1.11 % to 15.2% across the models. Remarkably, no sample fell into the "Poor" ($EWQI 100-150$) or "Very Poor" ($EWQI > 150$) categories as per the EWQI (MRA). However, the EWQI and EWQI (PCA) model identified 1 sample each as "Poor."

The data underscores disparities in sample distribution across different water quality classifications as determined by the three models. These variations highlight differences in assessment methodologies and criteria employed by each model, emphasizing the need for critical evaluation and contextualization of water quality assessments.

Table 5.4 Comparison of EWQI categories for Spring water samples.

Spring water type	EWQI Range	EW QI	EWQI (PCA)	EWQI (MRA)	EW QI	EWQI (PCA)	EWQI (MRA)
No of Samples				% of Samples			
Excellent	<25	525	544	525	73.0	75.7	73.2
Good	25-50	185	117	84	25.7	16.3	11.7
Moderate	50-100	8	57	110	1.11	7.92	15.2
Poor	100-150	1	1	0	0.14	0.14	0.00
Very Poor	>150	0	0	0	0.00	0.00	0.00

5.4.7. Spatial variability of Water Quality Assessment Using the EWQI, EWQI (PCA), and EWQI (MRA) models

The spatial distribution of spring water quality within the Ravi catchment revealed significant disparities, as evidenced by the distributions of the EWQI, EWQI (PCA), and EWQI (MRA) values illustrated in Fig. 5.27. The northwestern part exhibited substantially higher EWQI values compared to the southern, eastern, and southeastern regions, indicating a higher suitability of spring water for drinking purposes in the latter areas. Throughout the study area, both good and moderate quality spring water samples were observed, with a widespread distribution observed. Specifically, areas such as Bharmour, Palan in east predominantly featured good quality samples. In contrast, the central region of the Ravi River, encompassing locations like Ulansa, Mehla, and Gehra, predominantly contained moderate quality samples. However, the westernmost part of the study area encompassing locations like Chamba, exhibited spring water samples of poor and very poor quality, although these accounted for only a minor portion of the entire region. This distribution pattern suggests localized areas of compromised water quality amidst predominantly good to moderate quality samples.

Moreover, there was notable disparity in the spatial arrangement of spring water quality within the Ravi catchment, and the specific distributions of the EWQI, EWQI (PCA), and EWQI (MRA) can be seen in Fig. 5.27. Generally, the EWQI values in the

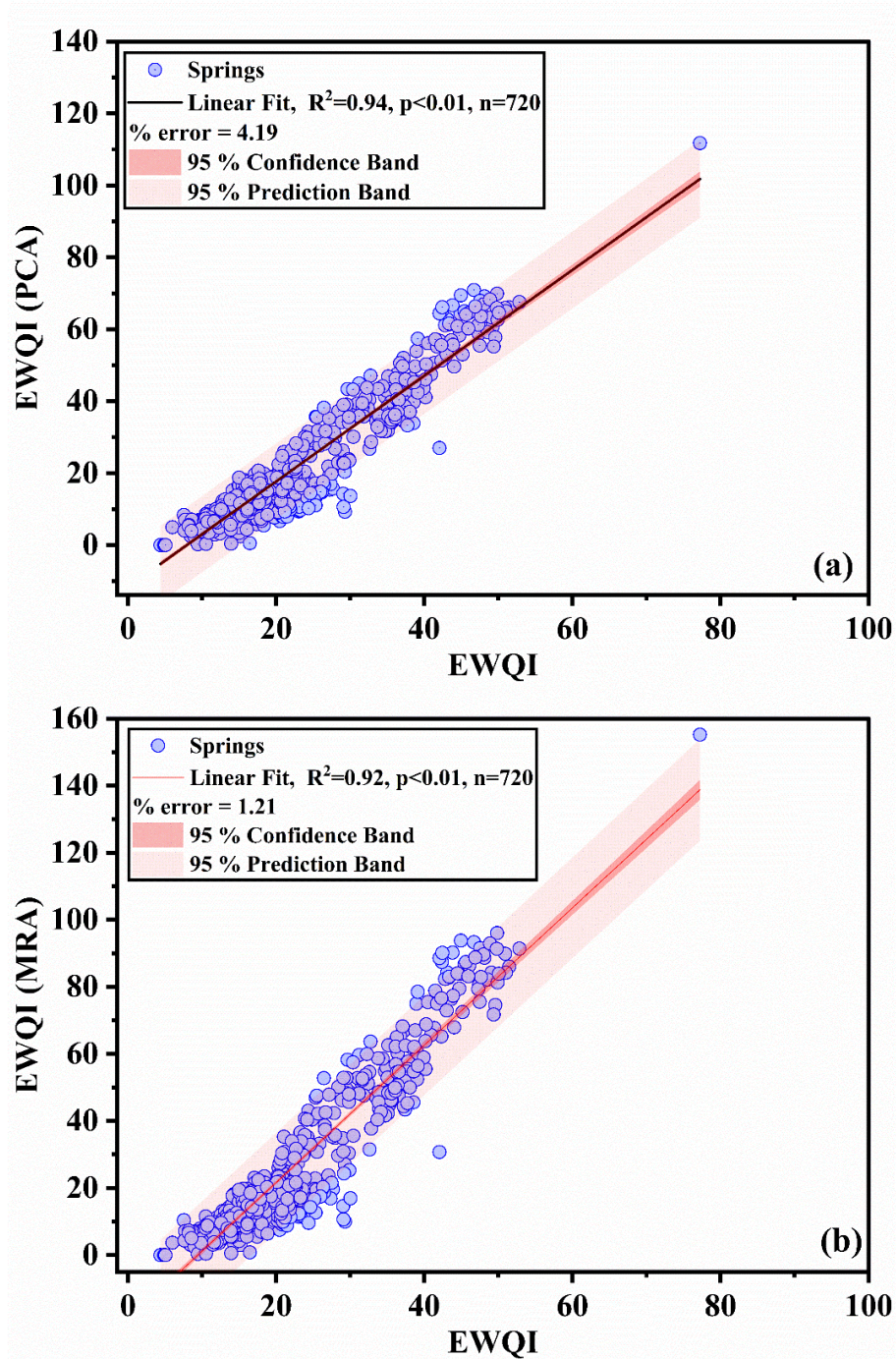


Fig. 5.27 Relationships between the Entropy Water Quality Index (EWQI) and the EWQI models derived from (a) Principal Component Analysis (PCA) and (b) Multiple Linear Regression (MLR).

northwestern part was substantially higher than those of the south, eastern and southeastern part (Fig. 5.28), indicating that spring water in the south and southeastern parts are more suitable for drinking. The distribution of good and moderate quality groundwater samples was widespread throughout the study area, with the good quality samples primarily located in the south and eastern parts on the contrary, the moderate quality samples were concentrated in the central area of the Ravi River. The westernmost part of the study area contained groundwater samples of poor and very poor quality, which accounted for a minor portion of the entire region (Fig. 5.28).

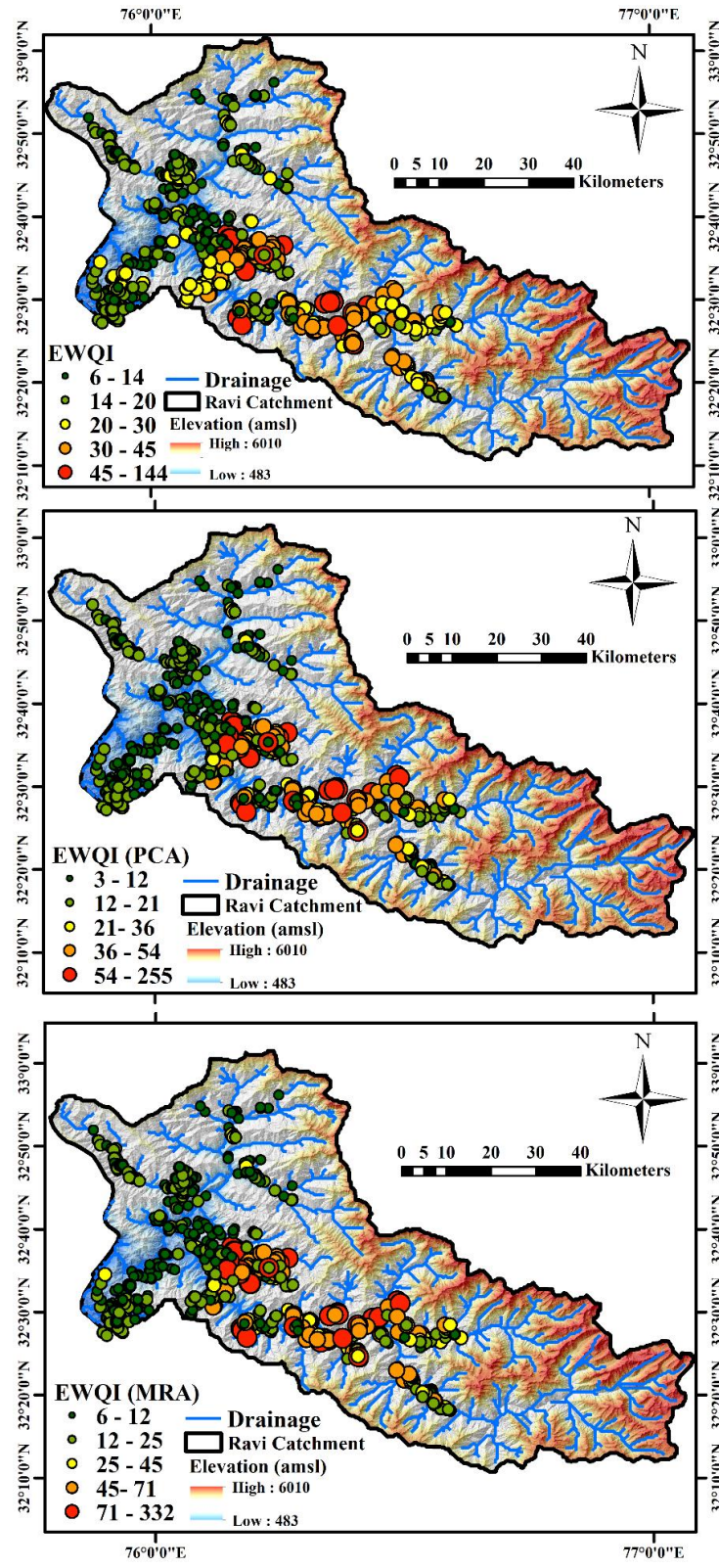


Fig. 5.28. Spatial variation in spring water quality in the Ravi catchment based on the EWQI, EWQI (PCA), and EWQI (MRA) models.

5.5. Seasonal variation of isotopic signatures in Precipitation

Table 5.5 provides a comprehensive summary of the isotopic composition of precipitation ($\delta^{18}\text{O}$ and $\delta^2\text{H}$ values) collected across various seasons and stations within the Ravi catchment. For instance, during the Pre-Monsoon (Pre-M) period in the Ravi catchment, the $\delta^{18}\text{O}$ values range from -17.5 to -6.6‰, with a mean of -13.8‰ and a standard deviation of 6.3. Similarly, the $\delta^2\text{H}$ values span from -128.9 to -38.0‰, with a mean of -98.5‰ and a standard deviation of 52.4. This indicates notable variability in isotopic composition during this season, likely influenced by diverse moisture sources and atmospheric processes.

In contrast, the Post Monsoon (Post-M) period exhibits relatively minor fluctuations in $\delta^{18}\text{O}$ values, maintaining a mean of -5.9‰, with a standard deviation of 0.02. The $\delta^2\text{H}$ values during this season range from -33.3 to -33.0‰, with a mean of -33.2‰ and a standard deviation of 0.1, suggesting a more homogeneous isotopic composition compared to other seasons.

During the Monsoon (M) season, the $\delta^{18}\text{O}$ values range from -17.5 to -5.5‰, with a mean of -11.0‰ and a standard deviation of 5.7. Correspondingly, the $\delta^2\text{H}$ values range from -130.5 to -31.1‰, with a mean of -76.0‰ and a standard deviation of 47.8, indicating significant variability influenced by seasonal precipitation patterns and moisture sources (Fig. 5.31).

The isotopic variability is further explored across different stations within the Ravi catchment area, such as Sherpur, Salooni/Bhedog, Kuran, Ghera, Sahu, and Holi (Fig. 5.30). Each station exhibits distinct patterns in isotopic composition during different seasons, reflecting the complex interplay of local climatic conditions, topography, and moisture sources.

Overall, this detailed summary of precipitation isotopes provides valuable insights into the spatial and temporal variability of isotopic composition within the Ravi catchment area. Such information is essential for understanding regional hydrological processes, assessing water resource sustainability, and informing effective water management strategies in the region.

Table. 5.5 Statistical summary of precipitation isotopes during Pre Monsoon (Pre-M), Post Monsoon (Post-M), and Monsoon (M) in the Ravi catchment.

Season and Stations		$\delta^{18}\text{O}$				$\delta^2\text{H}$			
		Min	Max	Mean	SD	Min	Max	Mean	SD
Ravi catchment									
	Pre-M	-17.5	-6.6	-13.8	6.3	-128.9	-38.0	-98.5	52.4
	Post-M	-5.9	-5.8	-5.9	0.02	-33.3	-33.0	-33.2	0.1
	M	-17.5	-5.5	-11.0	5.7	-130.5	-31.1	-76.0	47.8
1	Sherpur								
	Pre-M	-14.6	-6.4	-9.8	2.8	-103.7	-34.0	-64.1	23.4
	Post-M	-9.2	-1.3	-6.7	3.0	-67.4	-4.8	-48.6	23.2
	M	-14.8	1.0	-7.7	4.6	-102.8	14.9	-45.6	39.0
2	Salooni/Bhedog								
	Pre-M	-9.5	-5.8	-7.6	1.5	-66.7	-30.3	-48.9	14.7
	Post-M	-12.3	-3.3	-7.8	6.3	-83.0	-19.9	-51.4	44.6
	M	-15.5	-2.1	-9.5	3.8	-122.9	-6.3	-64.6	30.3
3	Kuran								
	Pre-M	-4.6	2.2	-0.9	3.3	-25.7	23.9	3.9	26.5
	Post-M	-9.0	-4.6	-7.9	2.2	-61.5	-33.1	-53.2	13.6
	M	-18.1	0.5	-7.5	4.8	-136.9	13.3	-49.4	39.4
4	Ghera								
	Pre-M	-9.5	-5.8	-7.6	1.5	-66.7	-30.3	-48.9	14.7
	Post-M	-12.3	-3.3	-7.8	6.3	-83.0	-19.9	-51.4	44.6
	M	-15.5	-2.1	-9.5	3.8	-122.9	-6.3	-64.6	30.3
5	Sahu								
	Pre-M	-10.6	-8.8	-9.3	0.9	-69.9	-55.0	-60.9	6.4
	Post-M	-13.4	-13.3	-13.3	0.0	-96.4	-94.8	-95.6	0.8
	M	-10.8	-5.8	-8.7	1.1	-71.6	-40.7	-57.1	6.9
6	Holi								
	Pre-M	-10.2	-2.8	-5.3	3.0	-81.8	-11.5	-34.5	28.1
	Post-M	-10.1	-9.7	-9.9	0.3	-67.6	-63.5	-65.6	2.9
	M	-13.8	-2.8	-9.3	3.9	-99.7	-11.5	-66.6	32.1

5.5.1. $\delta^{18}\text{O}$ - δD regression lines (Local Meteoric Water Lines)

Fig. 5.29 shows the $\delta^{18}\text{O}$ vs δD regression line (i.e., local meteoric water line - LMWL) for Pre-monsoon, post-monsoon, and monsoon rainwater samples for the Ravi catchment. The $\delta^{18}\text{O}$ - δD regression line equation for the pre-monsoon rain samples is: $\delta\text{D} = (7.93 \pm 0.15) \times \delta^{18}\text{O} + (11.51 \pm 0.4)$, for the post-monsoon rain samples is: $\delta\text{D} = (7.43 \pm 0.26) \times \delta^{18}\text{O} + (4.93 \pm 2.38)$, and for the monsoon season is $\delta\text{D} = (8.01 \pm 0.09) \times \delta^{18}\text{O} + (11.28 \pm 0.90)$. The LMWL for Ravi catchment is: $[\delta\text{D} = (8.0 \pm 0.07) \times \delta^{18}\text{O} + (10.87 \pm 0.73)]$ is comparable to the global meteoric water line (GMWL; Fig., 6.7). The $\delta^{18}\text{O}$ - δD regression lines for pre-monsoon and post-monsoon rain samples have different values of slope and intercept (Fig., 5.29)

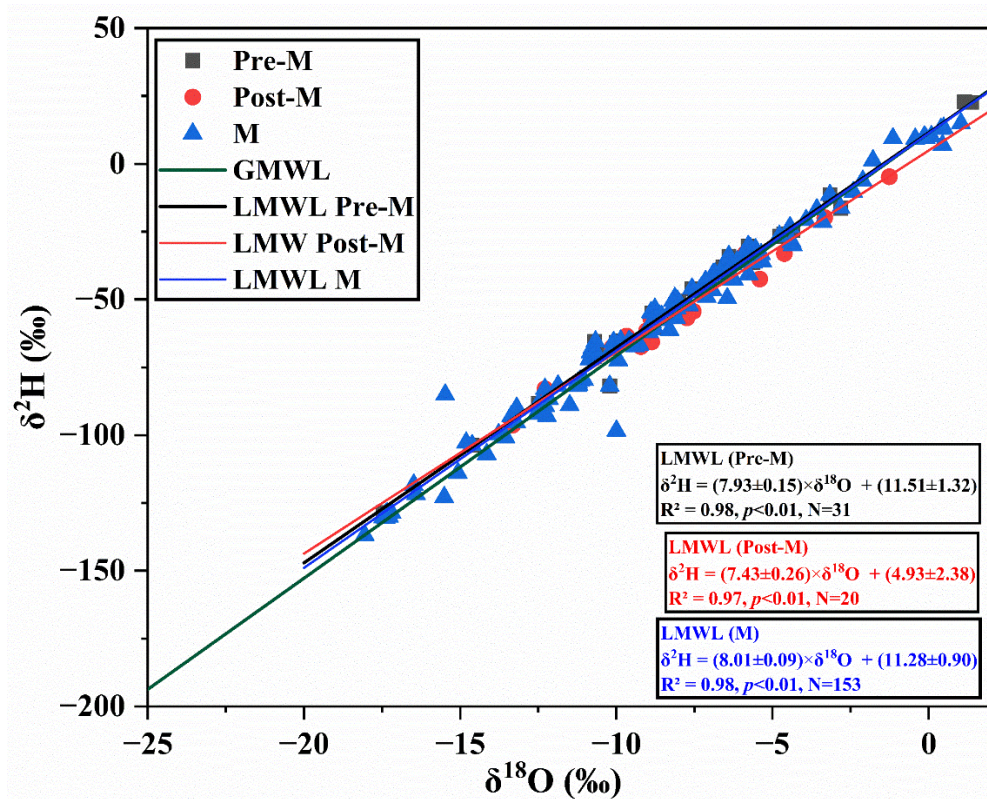


Fig. 5.29 $\delta^{18}\text{O}$ - $\delta^2\text{H}$ (a) Ordinary Least Squares Regression (OLSR) defining the LMWLs separately during Pre Monsoon (Pre-M), Monsoon (M), and Post Monsoon (M).

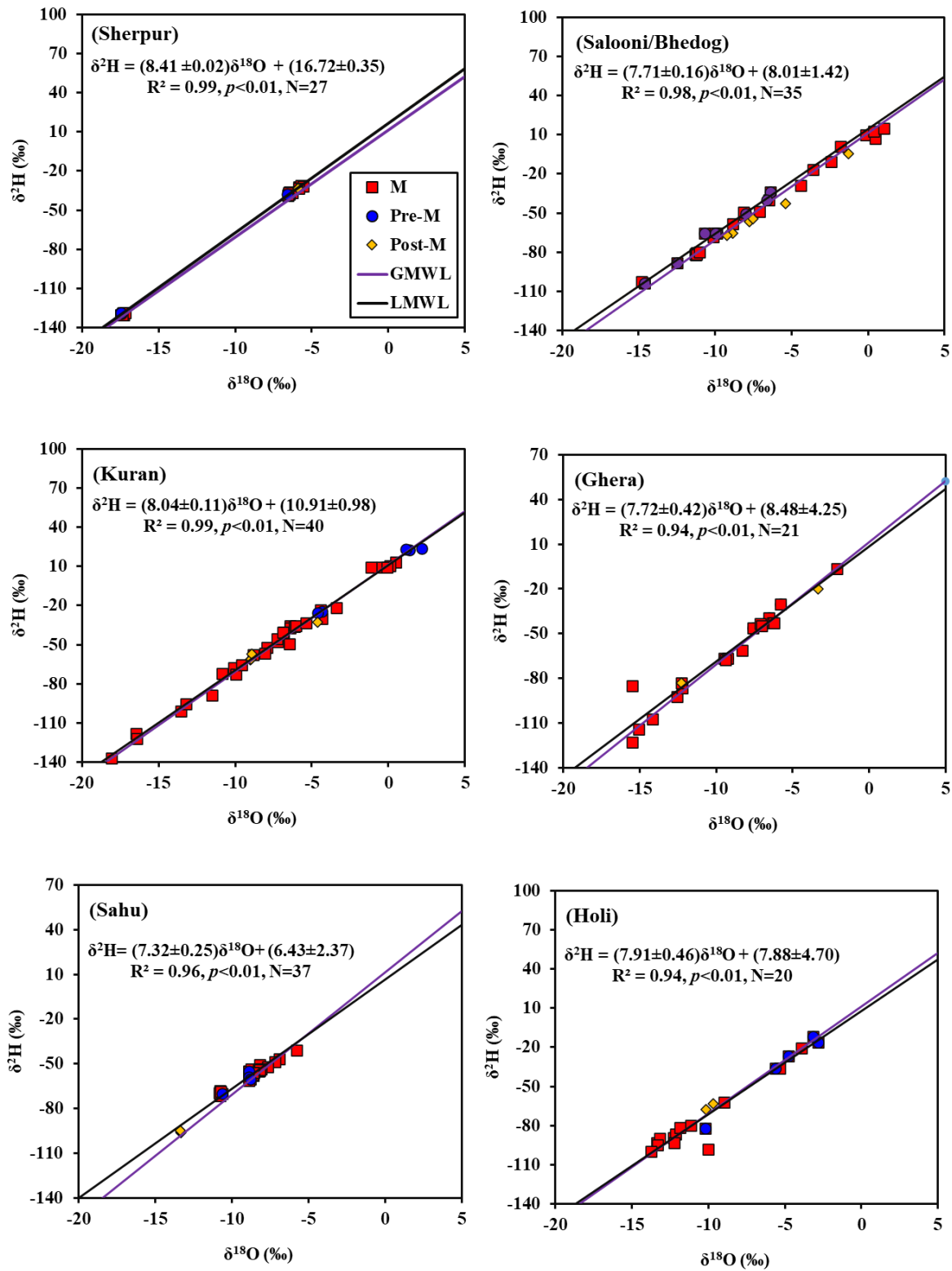


Fig. 5.30 $\delta^{18}\text{O}$ - $\delta^2\text{H}$ Ordinary Least Squares Regression (PWLSR) of samples collected at six stations of Ravi catchment collected during Pre Monsoon (Pre-M), Monsoon (M), and Post Monsoon (M).

The different slope of rain for different seasons indicates that the isotopic signature of rain changes seasonally. It is important to notice and realize that the seasonal change in rain isotopic composition evident from regression lines for the three seasons can be missed out if only mean values of the pre-monsoon and post-monsoon datasets are considered (Fig., 5.29). A close comparison of the seasonal regression lines (Fig., 5.29) reveals that the $\delta^{18}\text{O}$ - δD regression line slope for post-monsoon rain samples (7.43 ± 0.26) is lower than that of the LMWL (8.01 ± 0.09), indicating that rainwater undergoes considerable evaporation before and during infiltration while it becomes spring water. The combined effect of the local atmospheric processes is known to result in the evaporation of rainwater (Gupta and Deshpande, 2005; Dar et al., 2022). Another observation is that the slope of $\delta^{18}\text{O}$ - δD regression for Post-M rain samples (7.43 ± 0.26) is lower than that of Pre-M (7.93 ± 0.15). This indicates that the isotopic composition of rain changes during a long non-rainy, dry, post-M season.

5.5.2. Spatial variation of $\delta^{18}\text{O}$ and d-excess in spring water samples

The Table 5.6 presents the spatial variation of $\delta^{18}\text{O}$ and δD in spring water samples collected across different seasons and sites within the Ravi catchment area. During the Post-M period in the Ravi catchment, the $\delta^{18}\text{O}$ values range from -9.60 to -6.34‰, with a mean of -7.82‰ and a standard deviation of 0.98. The δD values span from -62.42 to -32.36‰, with a mean of -46.41‰ and a standard deviation of 8.26. These values indicate spatial variability in isotopic composition, likely influenced by local hydrological processes and recharge sources. Similarly, during the Monsoon (M) season, the $\delta^{18}\text{O}$ values range from -10.07 to -6.22‰, with a mean of -7.70‰ and a standard deviation of 0.96. The δD values range from -68.28 to -36.06‰, with a mean of -46.52‰ and a standard deviation of 7.46, suggesting comparable variability in isotopic composition compared to the Post-M period.

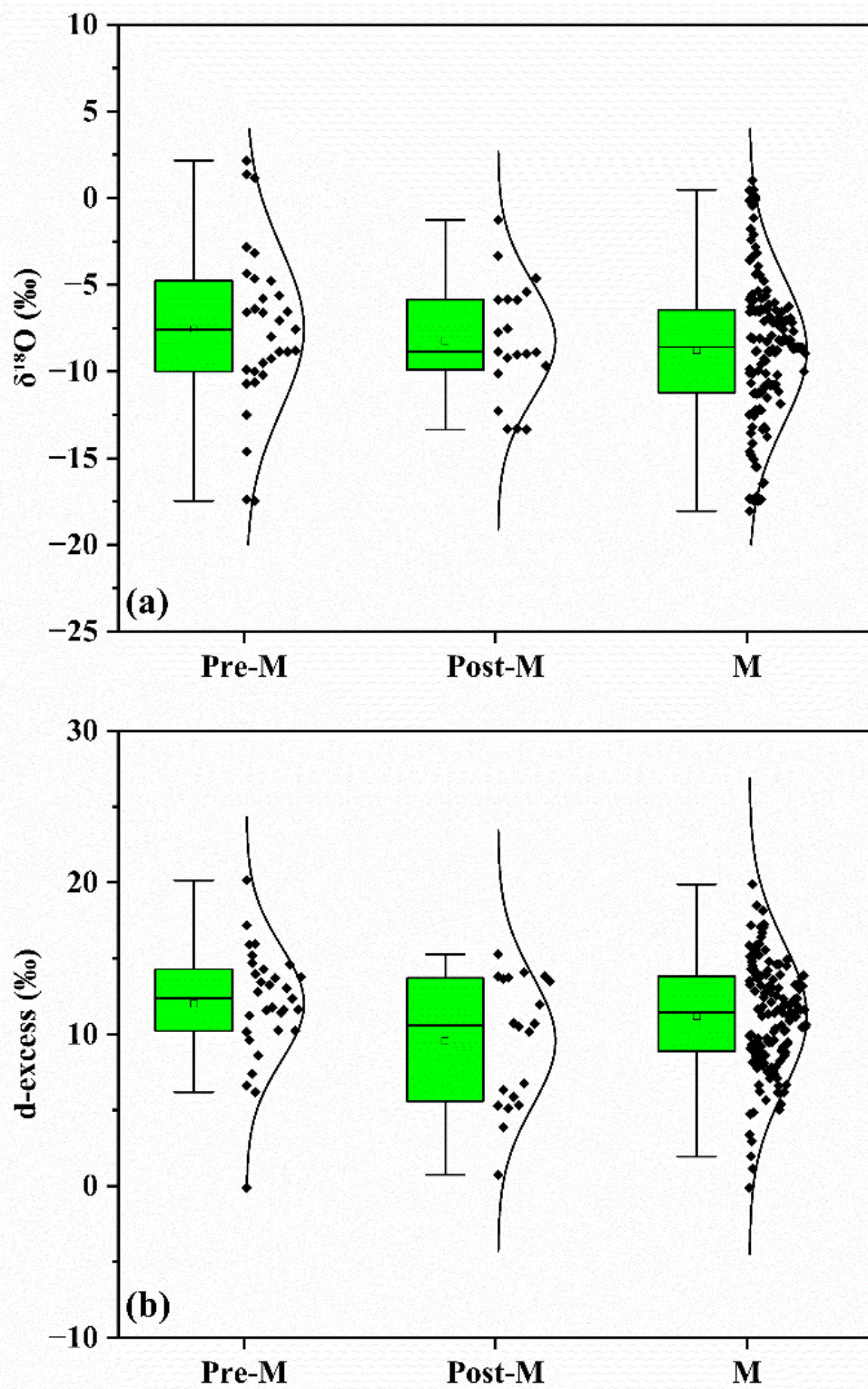


Fig. 5.31. The (a) $\delta^{18}\text{O}$ and (b) d-excess box and whisker plot for the three seasons during Pre Monsoon (Pre-M), Monsoon (M), and Post Monsoon (M).

Table. 5.6. Statistical summary of spring isotopes during Post Monsoon (Post-M), and Monsoon (M) in the Ravi catchment.

Season and Stations		$\delta^{18}\text{O}$				$\delta^2\text{H}$			
		Min	Max	Mean	SD	Min	Max	Mean	SD
	Ravi catchment								
	Post-M	-9.60	-6.34	-7.82	0.98	-62.42	-32.36	-46.41	8.26
	M	-10.07	-6.22	-7.70	0.96	-68.28	-36.06	-46.52	7.46
1	Sherpur								
	Post-M	-6.62	-6.52	-6.57	0.03	-38.07	-32.36	-36.13	1.58
	M	-6.73	-6.42	-6.57	0.08	-39.06	-36.19	-37.50	1.09
2	Salooni/Bhedog								
	Post-M	-7.33	-6.81	-6.90	0.16	-40.27	-35.02	-38.29	1.78
	M	-7.08	-6.80	-6.99	0.09	-43.88	-36.06	-40.53	2.09
3	Kuran								
	Post-M	-7.82	-7.58	-7.68	0.06	-46.01	-38.14	-43.07	2.19
	M	-7.82	-7.58	-7.68	0.06	-46.01	-38.14	-43.07	2.19
4	Sahu								
	Post-M	-7.19	-6.34	-6.77	0.26	-41.39	-36.69	-38.45	1.69
	M	-7.29	-6.22	-6.97	0.25	-46.56	-36.95	-41.81	2.74
5	Holi								
	Post-M	-9.51	-8.74	-9.12	0.24	-62.29	-52.02	-57.34	3.29
	M	-9.61	-8.96	-9.25	0.23	-61.09	-52.10	-56.98	2.58
6	NHPC surangini								
	Post-M	-7.41	-6.85	-7.26	0.15	-43.40	-36.23	-41.98	2.07
	M	-7.39	-7.28	-7.33	0.04	-43.88	-41.51	-42.76	0.83
7	GUWALA								
	Post-M	-8.97	-8.62	-8.83	0.11	-57.98	-51.41	-53.75	1.90
	M	-9.23	-8.60	-8.86	0.21	-57.44	-52.33	-53.90	1.60
8	Bharmour								
	Post-M	-9.60	-8.90	-9.39	0.19	-62.42	-57.34	-59.95	1.49
	M	-9.68	-8.90	-9.43	0.19	-64.37	-59.19	-60.82	1.43
9	Leech								
	Post-M	-7.84	-7.61	-7.70	0.07	-48.98	-44.78	-46.43	1.26
	M	-10.07	-6.86	-7.73	0.83	-68.28	-38.26	-46.57	7.47
10	Churu								
	Post-M	-7.70	-7.15	-7.54	0.15	-46.38	-44.40	-45.47	0.65
	M	-9.26	-6.32	-7.58	0.70	-61.61	-36.98	-45.05	6.22

Across different stations within the Ravi catchment area, significant variations in $\delta^{18}\text{O}$ and δD values are observed. For instance, at Sherpur during the Post-M period, the $\delta^{18}\text{O}$ values range from -6.62 to -6.52‰, with a mean of -6.57‰ and a standard deviation of 0.03. Meanwhile, the δD values range from -38.07 to -32.36‰, with a mean of -36.13‰ and a standard deviation of 1.58, indicating relatively homogeneous isotopic composition at this station during this season. Overall, the spatial variation of $\delta^{18}\text{O}$ and δD in spring water samples provides insights into the hydrological dynamics and recharge mechanisms within the Ravi catchment area, highlighting the influence of seasonal variations and local geological characteristics on isotopic composition. Figure 5.32 shows the seasonal variability of $\delta^{18}\text{O}$ and d-excess values in springs of Ravi catchment.

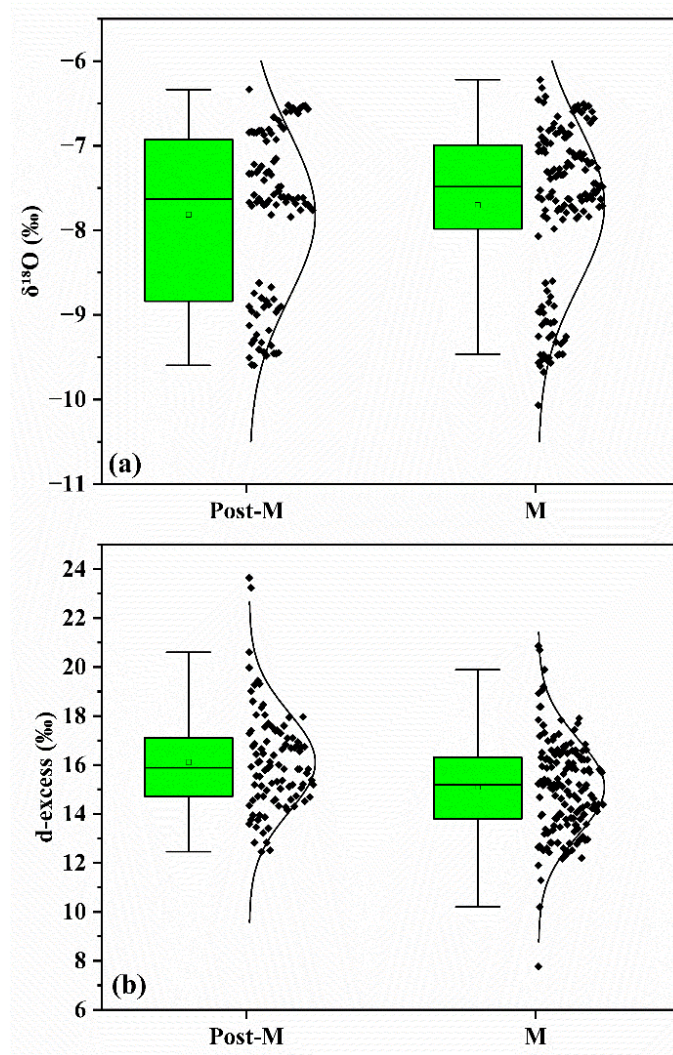


Fig. 5.32 The (a) $\delta^{18}\text{O}$ and (b) d-excess box and whisker plot for the two seasons during Monsoon (M), and Post Monsoon (M).

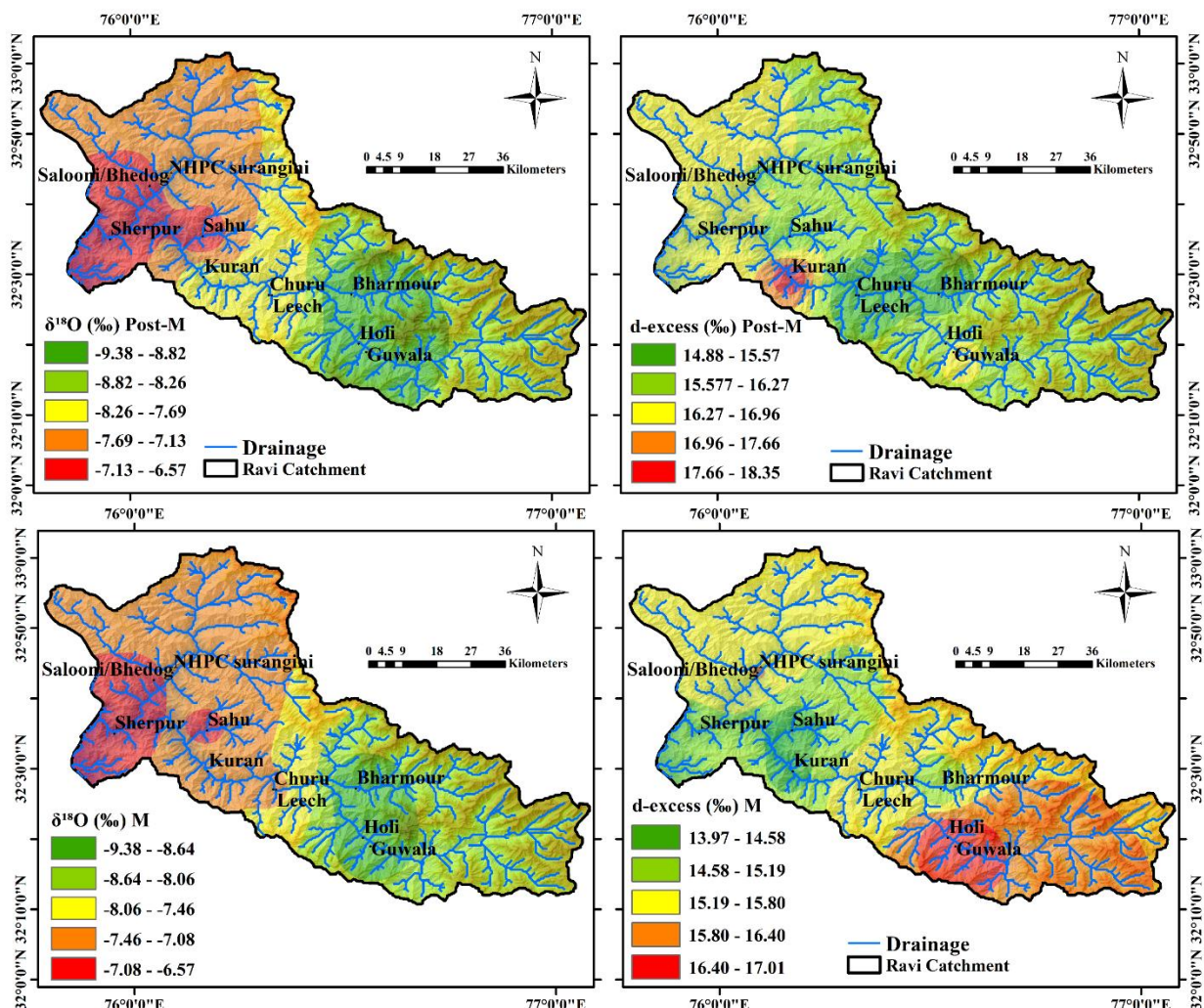


Fig. 5.33 Spatial variation in $\delta^{18}\text{O}$ and d-excess for post-monsoon (Post-M) and monsoon (M). The names of spring locations mentioned serve as reference points to illustrate the geographical distribution of isotopic values across the study area.

The spatial distribution of $\delta^{18}\text{O}$ for Post-M and M spring water samples is plotted in Fig. 5.33. The spring water samples in northwest region is isotopically enriched compared to southeast. The $\delta^{18}\text{O}$ values of spring are getting progressively depleted from -9.38‰ to 8.06 ‰ in the regions of Holi, Guwala and Bharmour, both Post-M and M seasons.

Spring water also shows the spatial variation in d-excess in Post-M and M (Fig. 5.33). During both seasons spring water in most of the areas show d-excess between 14.88 ‰ and 17.01 ‰, which is higher than the global average value of +10 ‰ (Craig, 1961) and suggests that the spring water is not very much prone to considerable evaporation or

recharge by considerably evaporated source water in the catchment. The higher d-excess and depleted patches in Holi and Guwala, $\delta^{18}\text{O}$ values in the M season clearly indicate freshwater influx from summer monsoon rain. The southeastern side of the study area shows higher d-excess and correspondingly lower $\delta^{18}\text{O}$ compared to northwestern part, where d-excess is lower and $\delta^{18}\text{O}$ is relatively high in M season. The spatial variability of $\delta^{18}\text{O}$ and d-excess in spring water indicates that, although ISM rainfall is known to be the source of spring water recharge, the rainfall in the region must undergo variable local effect before recharging the spring water in the region. Since the enriched $\delta^{18}\text{O}$ values both in rain (Table 6.5) and spring water (Sherpur) (Table 6.6) urbanized site suggest predominant evaporation.

5.5.3. Estimation of spring water recharge from rainfall

To estimate the contribution of Indian Summer Monsoon (ISM) rainfall to spring water recharge in the Ravi catchment, a two end-member mixing model is employed (Penna et al., 2017; Dar et al., 2024):

$$Q_{sp} = Q_{Pre-M} + Q_{Post-M} + Q_M \quad (5.1)$$

$$Q_{sp} = Q_{Pre-M} \times \delta_{Pre-M} + Q_{Post-M} \times \delta_{Post-M} + Q_M \times \delta_M \quad (5.2)$$

where Q_{sp} is the total recharge of spring and Q_{Pre} , Q_{Post-M} , Q_M are the recharge components and δ_{Pre-M} , δ_{Post-M} , δ_M are the tracer values ($\delta^{18}\text{O}$) during pre-monsoon, post monsoon and monsoon, respectively. Since no sample collection of springs were done during Pre-monsoon season and small precipitation is recorded during the Pre-Monsoon season as compared to post monsoon and monsoon, therefore negligible recharge of springs from rain is assumed to be contributed from pre-monsoon rainfall. Therefore, we estimated the contribution of rainfall only from Indian Summer monsoon rain and post-monsoon rain. By combining the equations of 6.1 and the contribution of rain from ISM rain is estimated as:

$$\text{Rain contribution during M (\%)} = Q_{ISM} = Q_{SP} \left(\frac{\delta_{Post-M}(spring) - \delta_M(rain)}{\delta_{MPost-M}(rain) - \delta_M(rain)} \right) \times 100 \quad (5.3)$$

The above end-member mixing model reveals that on average the Post-M spring water consists of an admixture of 62.45% of rainwater which mixes with 37.55% of the pre-monsoon spring water (Table 5.7) in the Ravi catchment. Variability in the rainwater contribution percentages across different stations (Fig. 5.34) reflect spatial differences in rainfall patterns, hydrogeological characteristics, and recharge mechanisms within the Ravi

catchment area. Understanding the spatial distribution of rainwater contributions to spring water is crucial for managing water resources effectively. It helps identify areas where groundwater recharge is primarily driven by rainfall, informing decisions related to water allocation, land use planning, and sustainable water management practices.

Table. 5.7 Rain contribution percentage for spring stations in the Ravi catchment

Springs/catchment	Rain Contribution from Monsoon rains (%)
Ravi catchment	62.45
Sherpur	86.96
Salooni/Bhedog	80.45
Kuran	-
Sahu	82.98
Holi	36.82
NHPC surangini	73.28
GUWALA	42.63
Bharmour	31.61
Leech	64.64
Churu	67.8

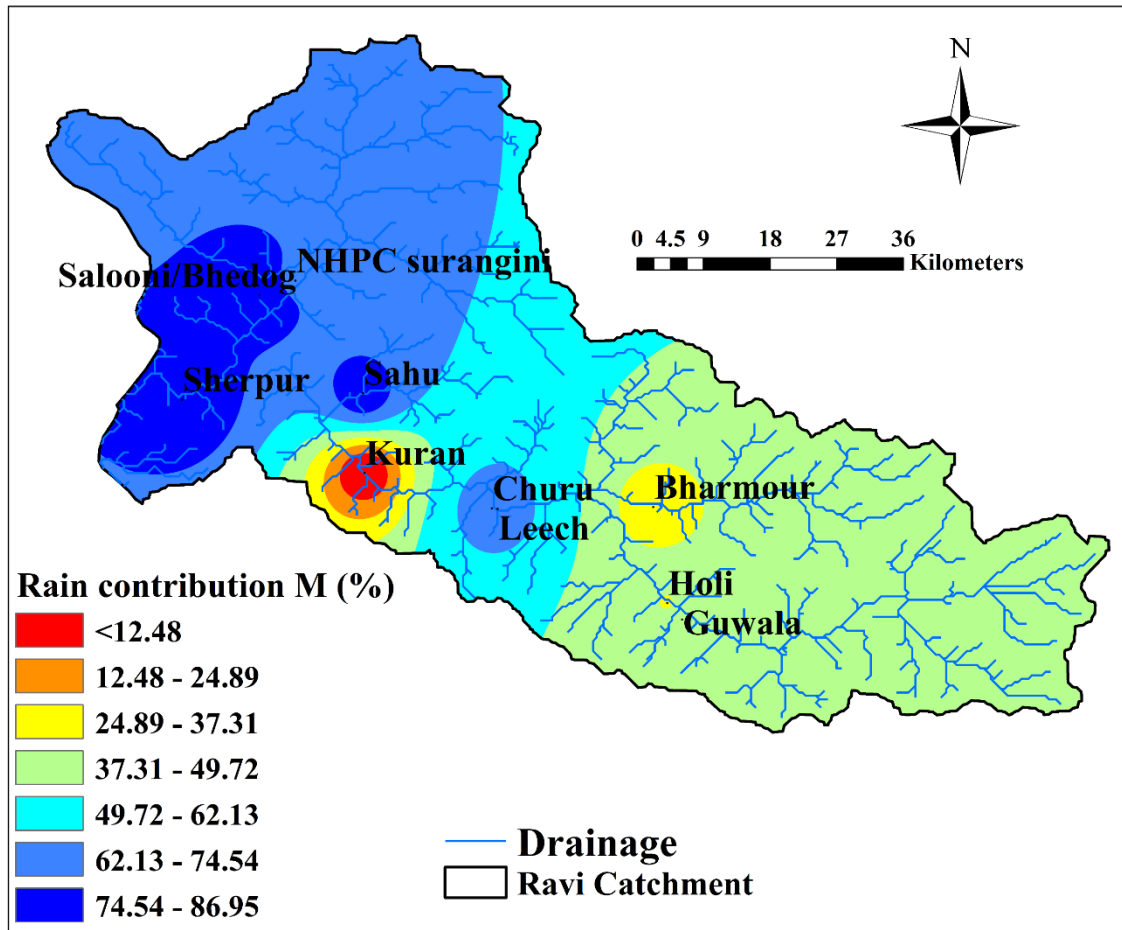


Fig. 5.34 figure illustrates the spatial variability in the percentage contribution of rainwater to post-monsoon spring water across various stations within the Ravi catchment area.

5.5.4. Conclusion

The isotopic analysis of rain and springs in the Ravi catchment area provides valuable insights into the hydrological dynamics of the region. Through a comprehensive examination of isotopic compositions, seasonal variations, and spatial distribution patterns, this chapter contributes to a deeper understanding of water resources in the Ravi catchment.

1. **Seasonal variation and isotopic signatures:** The analysis reveals significant seasonal variations in isotopic signatures of precipitation and spring water. Pre-monsoon, monsoon, and post-monsoon periods exhibit distinct isotopic compositions, reflecting variations in moisture sources, atmospheric processes, and recharge mechanisms.

2. **Local Meteoric Water Lines (LMWLs):** The $\delta^{18}\text{O}$ - δD regression lines provide insights into the relationships between isotopic parameters, facilitating the identification of local meteoric water lines (LMWLs) for different seasons. Variations in slope and intercept highlight seasonal changes in rainwater isotopic compositions and evaporation effects.
3. **Spatial variation in spring water isotopes:** The spatial distribution of $\delta^{18}\text{O}$ and δD in spring water samples elucidates the influence of local hydrological processes and geological characteristics on isotopic compositions. Variability across different stations underscores the complex interplay of factors shaping spring water recharge and isotopic signatures.
4. **Estimation of spring water recharge:** The end-member mixing model offers a quantitative assessment of rainwater contributions to spring water recharge. The analysis reveals that, on average, post-monsoon spring water in the Ravi catchment consists of approximately 62.45% rainwater, highlighting the significance of monsoon rains in groundwater recharge.
5. **Implications for water resource management:** Understanding the spatial and temporal variability of isotopic compositions is crucial for effective water resource management. It aids in identifying areas with high reliance on rainfall for groundwater recharge, informing sustainable water management practices, land use planning, and allocation decisions.

In conclusion, the isotopic analysis of Ravi Springs enhances our understanding of regional hydrological processes, facilitates informed decision-making in water resource management, and underscores the importance of considering isotopic signatures in assessing groundwater sustainability and resilience in the face of changing climatic conditions.

5.6. Identification of Typology and Possible Recharge Area of Some Selected Vulnerable Springs.

5.6.1 Identification of Typology

The above-mentioned methodology was followed and based on primary field and secondary data the typology of the springs is classified (Table 5.8).

Table 5.8 Classified typology and details of the springs in the study area

<i>Spring Id</i>	<i>Lithology</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Formation</i>	<i>Typology of the spring</i>
RS005	Phyllite	32.316307	76.55792	Chamba	Fracture
RS011	Phyllite~Slate	32.328083	76.554649	Manjir-Langera	Fracture
RS027	Phyllite	32.441202	76.461362	Manjir-Langera	Contact (Formation Contact)
RS032	Phyllite	32.439472	76.53121	Katarigali	Fracture/Drain
RS033	Phyllite	32.589818	76.171733	Manjir-Langera	Depression
RS054	Slate/Phyllite	32.588987	76.191867	Katarigali	Fracture/Contact
RS058	Slate/Phyllite	32.569773	76.253082	Katarigali	Fracture/Depression
RS061	Slate	32.382085	76.484082	Manjir-Langera	Depression
RS081	Schist/Phyllite	32.555021	76.121225	Morang	Fracture/Contact
RS084	Slate/Phyllite	32.568698	76.133443	Chamba	Fracture
RS089	Phyllite	32.449035	76.529495	Katarigali	Depression cum Fracture
RS097	Phyllite	32.609519	76.187321	Katarigali	Fracture
RS122	Shale Slate Sandstone	32.41113	76.405974	Manjir-Langera	Depression
RS154	Phyllite	32.604992	76.167553	Manjir-Langera	Depression cum Fracture
RS162	Slate/Phyllite	32.552785	76.123868	Chamba	Fracture
RS187	Phyllite	32.450404	76.328957	Chamba	Depression
RS219	Phyllite	32.570257	76.221308	Manjir-Langera	Fracture And Depression
RS223	Phyllite	32.4365	76.467439	Katarigali	Depression/Fracture
RS228	Slate/Phyllite	32.545151	76.140148	Chamba	Fracture
RS233	Phyllite	32.449686	76.336654	Chamba	Fracture
RS241	Slate	32.583184	76.141941	Chamba	Fracture
RS245	Schist	32.556992	76.11831	Morang	Fracture+Depression
RS287	Slate/Phyllite	32.362209	76.516644	Manjir-Langera	Fracture/Depression
RS300	Granite	32.520121	76.086677	Intrusives (Chamba/Dalho usie Granitoids)	Fracture
RS332	Phyllite	32.336699	76.541775	Manjir-Langera	Fracture

RS344	Shale Slate Sandstone	32.421964	76.404505	Manjir-Langera	Fracture
RS372	Schist	32.561066	76.117829	Morang	Fracture/Depression
RS399	Phyllite	32.569438	76.250453	Katarigali	Depression
RS410	Granitoid (Mahela)	32.476268	76.177764	Intrusives	Fracture/Depression
RS473	Shale/Limestone	32.581217	75.952267	Baila-Basantpur	Depression/Fracture (Karst components visible)
RS498	Phyllite	32.691955	76.054027	Chamba	Fracture
RS500	Shale Quartzite	32.593591	75.944266	Baila-Basantpur	Fracture
RS504	Schist	32.63363	76.007777	Morang	Fracture/Depression
RS511	Slate/Phyllite	32.663713	76.013781	Chamba	Fracture
RS525	Shale/Slate Sandstone	32.763444	75.968101	Manjir-Langera	Fracture/Contact
RS528	Phyllite	32.724873	76.089111	Katarigali	Fracture
RS534	Phyllite and slate reptation	32.710775	76.046273	Manjir-Langera	Depression
RS587	Slate and Phyllite reptation	32.594097	76.10821	Chamba	Fracture/Contact
RS884	Slate/ Quartzite and Limestone	32.509185	75.935804	Basantpur-Baila	Fracture
RS896	Sandstone/Shale reptation	32.510414	75.888797	Lower Murree	Fracture
E0015 1	Granitoid	32.4933355	76.1742264	Intrusives	Fracture/Depression
NSP 01	Granitoid	32.4943463	76.1736407	Intrusives	Depression

5.6.2. Hydrogeological investigation, demarcation of recharge area and suggested mitigation measures

Bherog spring (RS-534)

Bherog spring (RS-534) is located in Bherog village of Salooni block and about 55 km from Chamba on Chamba-Tista motor road. This spring is the sole source of water for the people of Bherog village. The general characteristics of the spring are given in Table 5.9. An aerial view of the spring is given in Fig 5.35.

Table 5.9. General characteristics of RS-534 spring.

Physiography and Structure	Spring emerges from Eastern facing slope.
Location	32°42'38.82"N, 76°02'96.93"E
Elevation	1274 m
Name of Village	Bherog
Rock Type	Phyllites with intercalated slates
Land ownership	Private ownership
Land cover	Agriculture land
Slope %	20-35
Slope Aspect	Eastern
Spring Type	Depression
Seasonality	Perennial
Discharge in LPM	4.83
TDS (ppm)	153
Dependence (HHs)	80
Use	Drinking, Domestic



Fig. 5.35 Synoptic view of spring RS-534 (marked with blue balloon) and adjoining area (google earth snapshot).

Hydrogeology of RS-534 spring site

The spring RS-534 is a primary water source in the Bherog and adjoining villages. The geographic attribute of the spring is 32°42'38.82"N, 76°02'96.93"E, and located at an altitude of 1274 m above sea level. Geologically the area lies in the proterozoic Manjir-Langera formation of the Haimanta group. The major litho-types in the area are slate, phyllite, and diamictite. The steep slopes are occupied by debris, and the rest of the area is covered by agricultural fields. The rocks are mainly exposed along the road cuts.

The rocks in the vicinity of the spring are phyllites with bands of the slates. During the field visit, it was observed that rocks were majorly dipping in the NE direction, and the prominent fracture set was dipping in the NNW & SW direction (Fig. 5.36). Most of the area is covered by the soil/ debris of diamictite affinity in the spring catchment area. The repetition of phyllite with the slate with significant planar discontinuities, viz. foliation, joints, and fractures is prominent in the area. The spring RS-534 emerges in the proximity of debris/soil and bedrock contact (Fig. 5.36). Since loose soil/debris occupies the majority of the area and the spring emerges from the topographic low, therefore, it is classified as a depression spring with contribution from contact as well.



Fig. 5.36 Field photographs a) Springs RS-534 discharge point; b) phyllite in immediate vicinity of spring; c) locally exposed ($32^{\circ}42'42.74''\text{N}$, $76^{\circ}02'45.32''\text{E}$) slate with dip direction (arrows) and fractures (dotted lines); d) folding phyllite and e) synoptic overview of the area with visible contact between debris and rock.

Demarcation of recharge area and suggested mitigation measures

From the discussion with stakeholders, it was evident that discharge of the spring has decreased significantly in the last 2 to 3 decades. Thus, spring rejuvenation might help to improve the groundwater condition in the whole springshed. Additionally, dependency of villagers on spring for drinking, washing, and cattle makes it suitable for recharge activities. As mentioned earlier, the rocks in the area belong to Manjir-Langera formation, which mainly comprises of phyllite, slates, and diamictites. The genetic nature of these lithounits allows low primary porosity except for diamictites. Therefore, the field fabrics, viz. foliation, joints, fractures, etc., control the hydraulic conductivity, or in simple words, these are the medium through which water flows. This is known as secondary porosity. However, the spring is surrounded by agricultural land that acts as the sink for meteoric water thereby aiding the groundwater recharge during the farming seasons.

To demarcate the recharge area of the spring RS-534, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. The majority of dominant planar structures viz. foliation dip in the NE direction and the major joints dip in the NNW and SW directions, respectively. The cross-section with a conceptual model (Fig. 5.37) is also given to appreciate the geological architecture in the vicinity of the spring. Thus, considering complex geomorphology and field structural geological data recharge area was demarcated (Fig. 5.38). Additionally, the percolation of the water through the agricultural fields and debris will also have a bearing on spring recharge. Subsequently, it is proposed that activities related to rainwater harvesting or other interventions should be endorsed in and around the area demarcated as the recharge area.

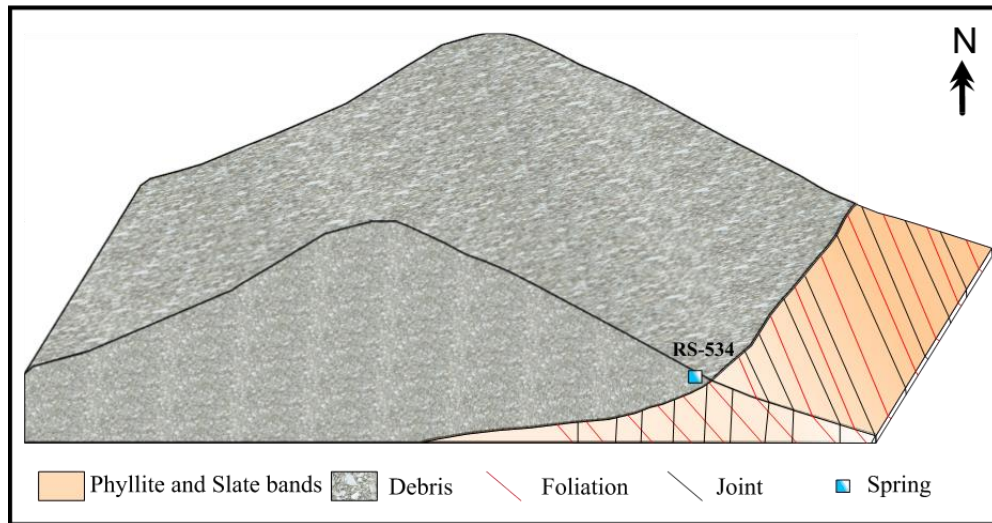


Fig. 5.37. Schematic cross section (not to the scale).

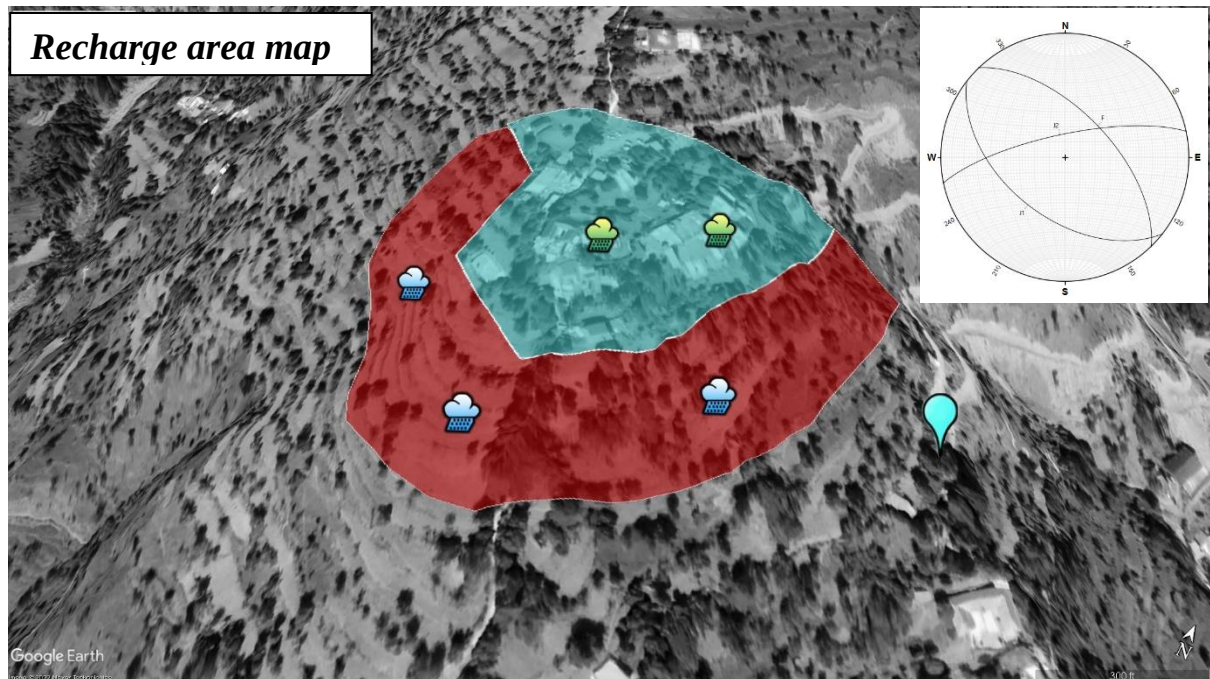


Fig. 5.38 The plausible recharge area is demarcated in the red and blue polygon. The red polygon is the area where trenches and pits can be constructed. A blue polygon demarcates the area where rooftop rainwater harvesting measures can be adopted to rejuvenate the spring RS-534 (marked in the blue balloon).

Since the majority of the area in recharge areas are agricultural fields, it would not be easy to convince the people of any supply-side activity. Villagers have been managing this source for ages and are entirely dependent on it during the lean season. This fluctuation

in discharge during the peak and lean seasons can be attributed to the variability of the precipitation. Furthermore, new road construction has also added a dynamic component to the hydrogeology of the springshed. However, nearby households are at a distance enough to avoid any contamination. Thus, all the above points should be considered while planning the spring rejuvenation activities in the area. Therefore, it is recommended to go for structures like trenches along with the retaining wall. Furthermore, sloping inward bench terraces will be suitable to conserve the moisture having It will not only recharge the source but also hold the moisture content for the crops. Shoulder bunds are also to be constructed at the outer edge of the bench terraces, to hold the runoff over the top of the terrace, and also to provide stability to the terrace.

Chambi spring (RS-154)

Chambi spring (RS-154) is located in Chambi village of Chamba block and about 20 km from Chamba on Chamba-Saho motor road. This is depression cum fracture type of spring emerged at eastern facing slope. People of Chambi village are generally use the spring water for drinking purpose. The general characteristics of the spring are given in Table 5.10. An aerial view of the spring is given in Fig 5.39.

Table 5.10 General characteristics of RS-154 spring.

Physiography And Structure	Spring emerges from Eastern facing slope.
Location	32°36'17.95"N, 76°10' 02.89"E
Elevation	1277 m
Name of Village	Chambi
Rock Type	Slate and Phyllite
Land ownership	Private/Govt. ownership
Land cover	Forest/Agriculture land
Slope %	40-60
Slope Aspect	Eastern
Spring Type	Depression cum fracture
Seasonality	Perennial
Discharge in LPM	6.42
TDS	400
pH	7.18
Dependence (HHs)	20
Use	Drinking, Domestic



Fig. 5.39. Synoptic view of spring RS-154 (marked with blue balloon) and adjoining area (google earth snapshot)

Hydrogeology of RS-154 spring site

The spring RS-154 is a primary source of water in the Chambi village. The geographic attribute of the spring is 32°36'17.95"N, 76°10' 02.89"E with a height of 1277 m above sea level. Geologically, the area lies in the Manjir-Langera formation of the Neoproterozoic Haimanta group. The spring is near the contact zone between Chamba and Manjir-Langera formations. The major litho-types in the area are phyllite diamictite, shale, slate, sandstone, and limestone. The landuse of the area includes agricultural land and forest land. The rugged topography (with steep slopes) and quaternary debris are the key geomorphological elements of the catchment area. The rocks are mainly exposed along the road cuts and drainage (Fig. 5.40).



Fig. 5.40 Field photographs a) field photo of spring RS-154; b) field exposure of slates; c) field exposure of phyllites; and d) exposure of slate along the drainage.

The rocks in the vicinity of the spring are slates of Manjir-Langera formation (field photographs; Fig. 5.40b), the field fabrics viz. foliation, joints, and fractures prominent in the litho units of the area. During the field visit, it was observed that rocks were majorly dipping moderately to low in the NNE direction while the prominent fracture set dipped in the NE and SW direction. The contact between the debris and strata is also seen (Fig. 5.40a & b). In the proximity of spring slates and phyllites exhibit pervasive planar discontinuities viz., foliation, joints, and fractures. The spring RS-154 emerges through the debris/soil. Integrating the field observation and geomorphological data it is inferred that RS-154 is a depression cum fracture spring.

Demarcation of recharge area and suggested mitigation measures

Spring RS-154 is central to nearby inhabitants; however, on discussion with stakeholders, it was evident that discharge has decreased significantly in the last few decades. Furthermore, a decrease in discharge after the earthquakes was highlighted by the inhabitants, which could be attributed to the proximity of spring to lithological contact between the Vaikrita and Haimanta groups of rocks. The dependency of villagers on spring for drinking, washing, and cattle makes it suitable for recharge activities. As mentioned earlier, the rocks in the area belong to the Manjir-Langera formation, which mainly comprises of phyllite diamictite, shale, slate, sandstone and limestone. The intrinsic nature of these litho-units allows low primary porosity except for diamictites. Therefore, the field fabrics, viz. foliation, joints, fractures, etc., control the hydraulic conductivity, or in simple words, these are the medium through which water flows. This is known as secondary porosity. However, the spring is surrounded by agricultural land that acts as the sink for meteoric water that facilitates groundwater recharge during the farming seasons.

To demarcate the recharge area of the spring RS-154, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. It was evident from the fieldwork that the majority of dominant planar structures viz. foliation dip in the NE direction and prominent fracture set in SW direction. However, general groundwater flows in NW to N direction (Fig 5.41); as observed from ground water flow in spring. Thus, considering complex geomorphology and field structural geological data recharge area was demarcated (Fig. 5.42). Subsequently, it is proposed that activities related to rainwater harvesting or other types of interventions should be endorsed in and around the area demarcated as the recharge area. The cross-section with a conceptual model is also given (fig. 5.41).

The catchment area includes agricultural fields, drainage, and a steep slope. Percolation of the water through the agricultural fields and debris will also contribute to the spring recharge. Notably, a steep slope in the catchment will hamper the construction of recharge structures. However, constructing a small check dam in the nearby drainages can also help increase the residence time of surface runoff and in turn enhance the discharge of spring. The presence of agricultural fields and dependence on forest (including grass on slopes) for cattle fodder will require community mobilization for recharge activities.

Villagers have been managing this source for ages and are entirely dependent on it during the lean season. The fluctuation in discharge during the peak and lean seasons can be attributed to the variability of the precipitation. Furthermore, nearby households are at a distance enough to avoid any contamination. Thus, all the above points should be considered while planning the spring rejuvenation activities in the area. Therefore, it is recommended to go for structures like trenches along the retaining wall and small check dams in the nearby drainages. It will not only recharge the source but also hold the moisture content for the crops.

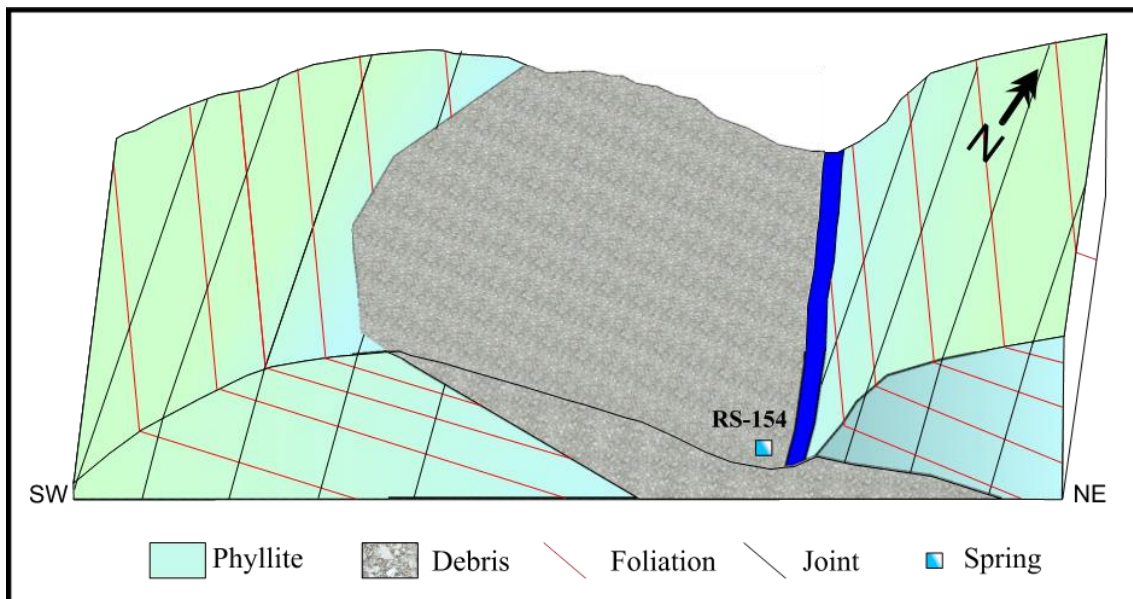


Fig. 5.41. Schematic cross section (not to the scale).

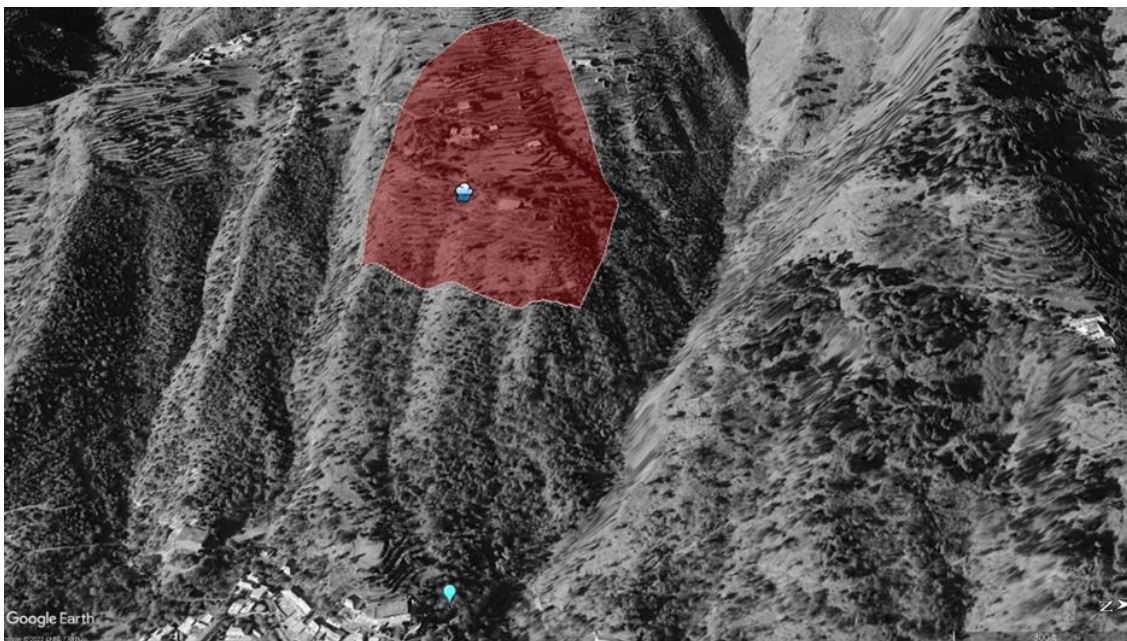


Fig. 5.42 The plausible recharge area is demarcated in the red polygon. The red polygon is the area where trenches and pits can be constructed to increase the percolation of water for the rejuvenation of spring RS-154 (marked in the blue balloon).

Chaminoo spring (RS-033)

Chaminoo spring (RS-033) is located in Chaminoo village of Chamba block and about 15 km from Chamba on Chamba-Saho motor road. This is depression type of spring emerged at eastern facing slope. People of Chaminoo village and local *dhabas* are generally use the spring water for drinking purpose. The general characteristics of the spring are given in Table 5.11. An aerial view of the spring is given in Fig 5.43.

Table 5.11 General characteristics of Chaminoo (RS-033) spring.

Physiography & Structure	Spring emerges from North Eastern facing slope
Location (Lat/Long)	32°35'23.74"N, 76°10' 18.62"E
Elevation (m, amsl)	1045
Name of Village	Chaminoo
Rock Type	Phyllite
Land ownership	Private Land
Land cover	Agriculture land
Slope %	20-40

Slope Aspect	Eastern
Spring Type	Depression
Seasonality	Perennial
Discharge (LPM)	8.18
pH	7.9
TDS (mg/l)	328
Dependence (HHs)	30 + Passerby
Use	Drinking, Domestic

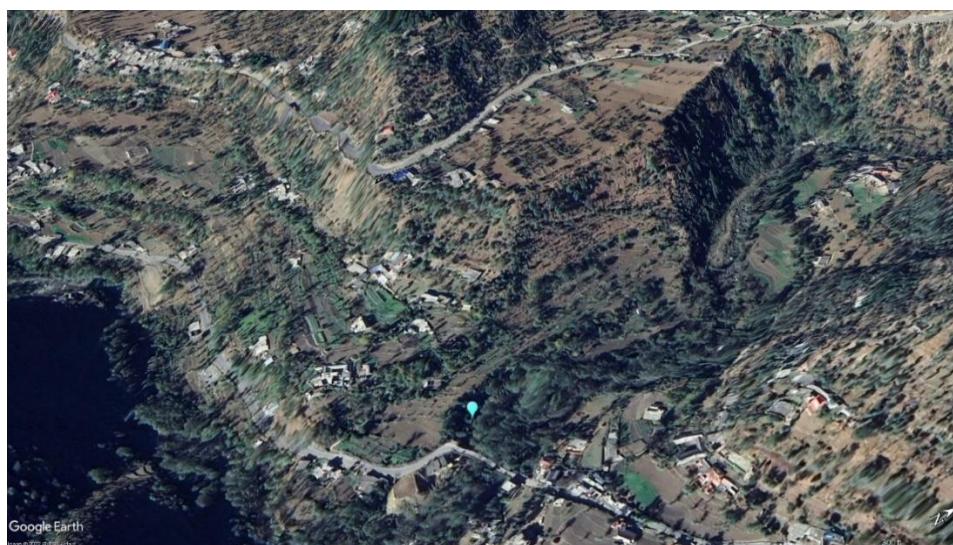


Fig. 5.43 Showing synoptic view of spring RS-033 (marked with blue balloon) and adjoining area (google earth snapshot)

Hydrogeology of RS-033 spring site

The spring RS-033 is a primary water source in the Chaminoo village and local *dhabas* located on road. The geographic attribute of the spring is 32°35'23.74"N, 76°10'18.62"E, and located at an altitude of 1045 m, amsl. Geologically, the area lies in the Manjir-Langera formation of the Neoproterozoic Haimanta group. The spring is near the contact zone between Chamba and Manjir-Langera formations. The major litho-types are phyllite, diamictite, shale, slate, sandstone, limestone. In the springshed agricultural fields constitute the major landuse of the area. The major geomorphic elements of the catchment area are the quaternary debris (with diamictite affinity), low to moderate slope, and perennial drainage.

The rocks are mainly exposed along the road cuts and drainage (Fig. 5.44). The spring outcrops through the debris (Fig. 5.44a). Since loose soil/debris occupies most of the area and the spring emerges from the topographic low, it is classified as a depression spring. The rocks in the vicinity of the spring are of Manjir-Langera formation, the field fabrics viz. foliation, joints, and fractures are prominent in the lithounits of the area. During the field visit, it was observed that rocks were majorly dipping moderately to low in the NNE direction while the prominent fracture set was dipping in the SE direction and SSW direction. The contact between the debris and strata is also seen (Fig. 5.44b).

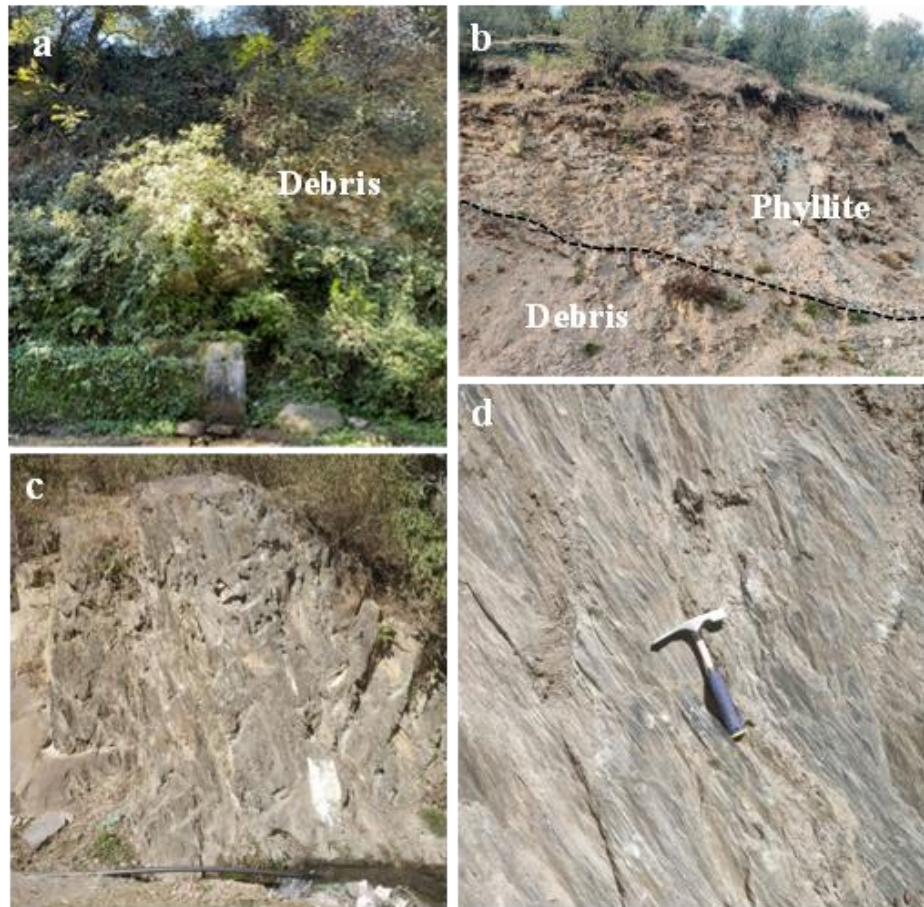


Fig.5.44. Field photographs a) field photo of spring RS-033; b) field exposure of phyllite with debris and phyllite contact; c) and d) field exposure of phyllites

Demarcation of recharge area and suggested mitigation measures

Spring RS-033 is central to nearby inhabitants; however, on discussion with stakeholders, it was evident that discharge has decreased significantly in the last 2 to 3 decades. Thus, the spring rejuvenation might help to improve the groundwater condition

in the springshed as a whole. The landholding in the catchment area is private and is majorly used for agricultural purposes. The average slope of the area is low. The villagers' dependency on spring for drinking, washing, and cattle makes it suitable for recharge activities. As mentioned earlier, the rocks in the area belong to the Manjir-Langera formation, which mainly comprises phyllite, slates, and diamictites. The intrinsic nature of these litho-units allows low primary porosity except for debris/diamictites. Ideally, the field fabrics, viz. foliation, joints, fractures, etc., control the hydraulic conductivity, or in simple words, these are the medium through which water flows. This is known as secondary porosity. However, the spring is surrounded by agricultural land that acts as the sink for meteoric water also facilitates groundwater recharge during the farming seasons. On discussion, some stakeholders claim an anomalous increase in the spring discharge during the lean season. The increase in discharge could be attributed to the seepage from the canal during irrigation period in the upper reaches of the catchment area. Additionally, it suggests that any intervention in this area will ultimately benefit the recharge of the source.

To demarcate the recharge area of the spring RS-033, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. Based on the field information the conceptual model of the spring is prepared and visualized in Fig.5.45. Since the majority of the area is occupied by the agricultural fields, therefore, percolation of the water through agricultural fields and debris will have a bearing on the spring recharge. Based on the above information, the recharge area was demarcated (Fig. 5.46). Subsequently, it is proposed that activities related to rainwater harvesting, viz. rooftop rainwater harvesting and trenches along the side of the agricultural fields, should be endorsed in and around the area demarcated as the recharge area.

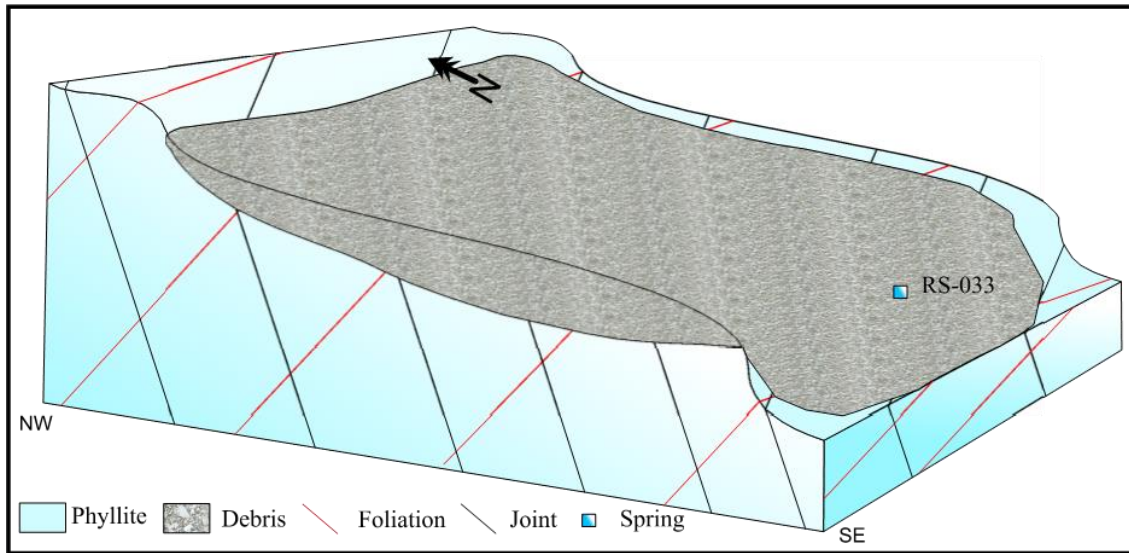


Fig. 5.45 Schematic cross section (not to the scale).

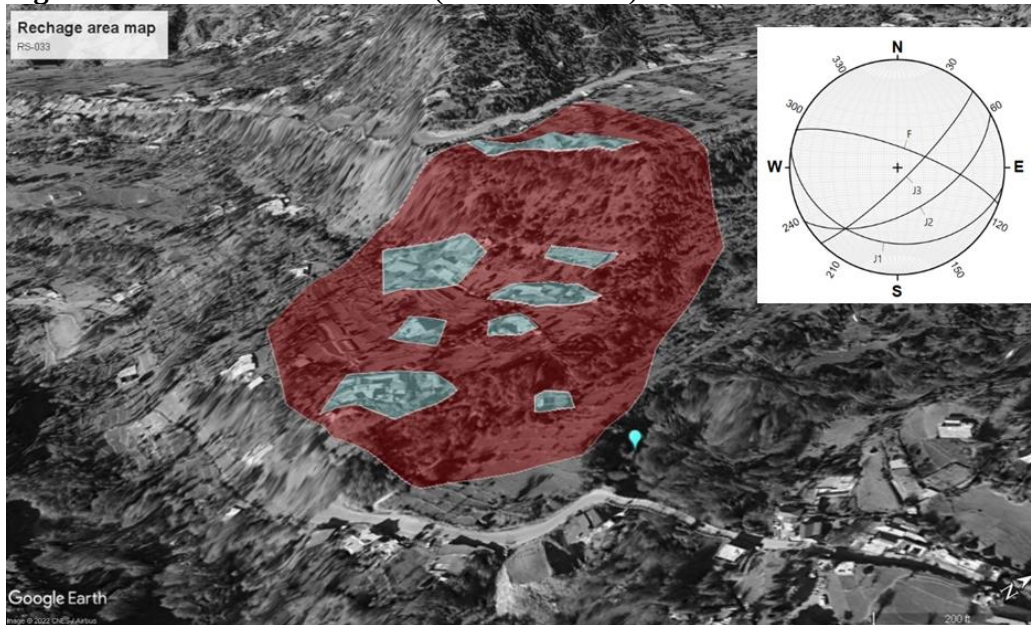


Fig. 5.46. The plausible recharge area is demarcated in the red and blue polygon. The red polygon is the areas where trenches and pits can be constructed. A blue polygon demarcates the area where rooftop rainwater harvesting measures can be adopted to rejuvenate the spring RS-033 (marked in the blue balloon).

Lech spring (RS-233)

Lech spring (Rs-233) is a very low discharge spring but the villagers of the Lech solely depend on it for drinking purpose. The water of the Lech spring is sweet and cold in summer due to which people are like to drink the water from the spring even having the pipe water supply in the village. General characteristics observed during the field visits are given in Table 5.12. Bird's eye view of the Lech spring is depicted in the Fig. 5.47.

Table 5.12. General characteristics of RS-233 spring.

Physiography and Structure	Spring emerges from South West facing slope
Location (Lat/Long)	32°26'58.95"N, 76°20' 11.97"E
Elevation (m, amsl)	1315 m
Name of Village	Lech
Rock Type	Slate with Phyllite interbands
Land ownership	Private/Govt. ownership
Land cover	Forest/Agriculture land
Slope (%)	30-60
Slope Aspect	Southern
Spring Type	Fracture
Seasonality	Perennial
Discharge (LPM)	0.65
TDS (mg/l)	190
Dependence (HHs)	20
Use	Drinking, Domestic

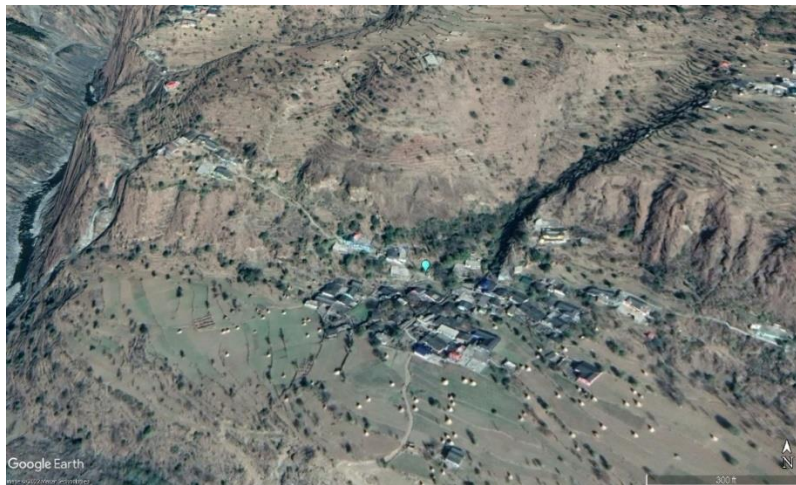


Fig.5.47. Showing synoptic view of spring RS-233 (marked with blue balloon) and adjoining area (google earth snapshot)

Hydrogeology of RS-233 spring site

The spring RS-233 is a primary source of water in the Lech village. The geographic attribute of the spring is 32°26'58.95"N, 76°20' 11.97"E, and is located at an altitude of

1351 m, amsl. Geologically, the area lies in the Chamba formation of Vaikrita group. The major litho-types in the area are carbonaceous slate, phyllite and quartzite. The landuse of the area includes agricultural land and forest land. The rugged topography (with steep slopes) and quaternary debris are the key geomorphological elements of the catchment area. The rocks are mainly exposed along the trails and drainage.

The rocks in the vicinity of the spring are slates with interbedded phyllites of Chamba formation, the field fabrics viz. foliation, joints, and fractures prominent in the litho-units of the area. During the field visit, it was observed that rocks were majorly dipping moderately to low in the NE direction while the prominent fracture set dipped in the ENW and SW direction.



Fig.5.48. Field photographs a) field photo of spring RS-233; b) field photograph of slate in the vicinity of the spring; c) nearby spring; d) field exposure of slates near the spring RS-233

In the proximity of spring slate and phyllite with significant planar discontinuities, viz. foliation, joints, and fractures are documented. The spring RS-233 emerges through the debris/soil. Additionally, the field fabrics (foliation, joints, and fractures) and steep topography dictate the groundwater flow in the catchment area. In the view of the field geological and geomorphological observations RS-233 was classified as a fracture spring.

Demarcation of recharge area and suggested mitigation measures

Spring RS-233 is central to nearby inhabitants; however, on discussion with stakeholders, it was evident that discharge has decreased in the last decade. The spring in immediate proximity of the RS-233, exhibits the shifting of the source (Fig. 5.48 c), which could be attributed to the disturbance in local geological architecture due to earthquakes or subsidence related phenomenon. The villagers' high dependency on spring for drinking, makes it suitable for recharge activities. As mentioned earlier, rocks in the area belong to the Chamba formation, which mainly comprises carbonaceous slate, phyllite, and quartzite. A carbonaceous slate occupies the area in proximity to the spring along with the phyllites. The intrinsic nature of these litho-units allows low primary porosity. Therefore, the field fabrics, viz. foliation, joints, fractures, etc., control the hydraulic conductivity, or in simple words, these are the medium through which water flows. This is known as secondary porosity. The houses are nearby, which could contribute to the contamination of the source in the near future. Spring emerges through a topographic low, and the landuse is mixed along with a quaternary deposit in the catchment area. Agricultural land/quaternary deposits also act as the sink for meteoric water that facilitates groundwater recharge during the farming seasons.

To demarcate the recharge area of spring RS-233, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. It was evident from the fieldwork that general groundwater flow will be facilitated along the NE direction as the dominant planar structures dip in the NE direction (Fig. 5.49). Additionally, the percolation of the water through the agricultural fields and debris will also affect spring recharge. It is noteworthy that steep slope in catchment will not be suitable for construction of engineering structures. However, constructing small check dam in the nearby drainages can be helpful in increasing the residence time of surface runoff. Thus, considering complex geomorphology and field structural geological data recharge area was demarcated (Fig. 5.50). Subsequently, it is proposed that activities related to rainwater harvesting or other interventions should be endorsed in and around the area demarcated as the recharge area. The cross-section with a conceptual model is also given to appreciate the geological architecture in the vicinity of the spring (fig.5.49).

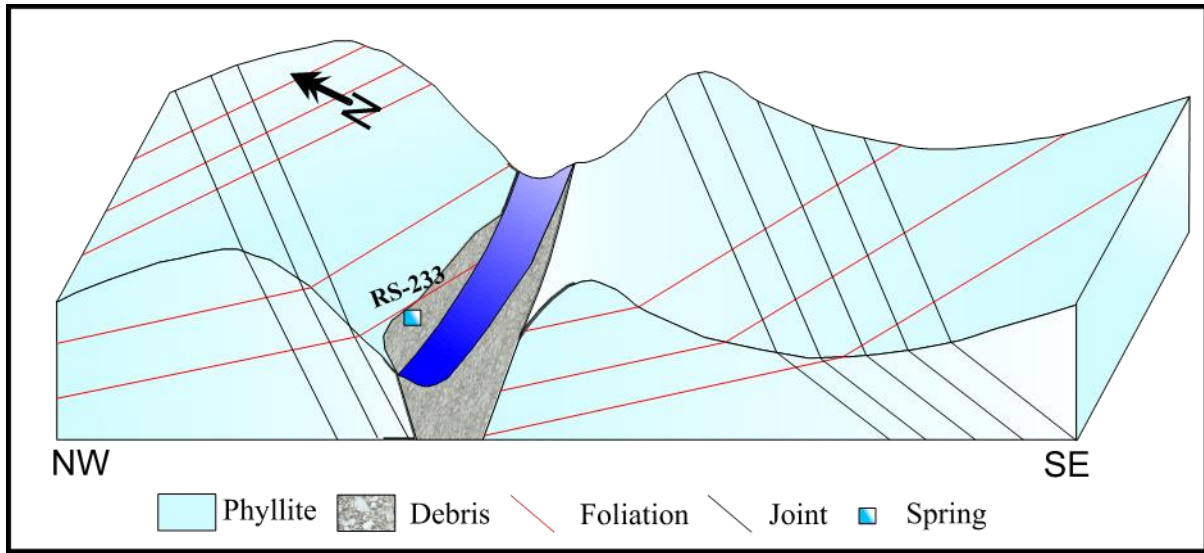


Fig. 5.49. Schematic cross section (not to the scale).

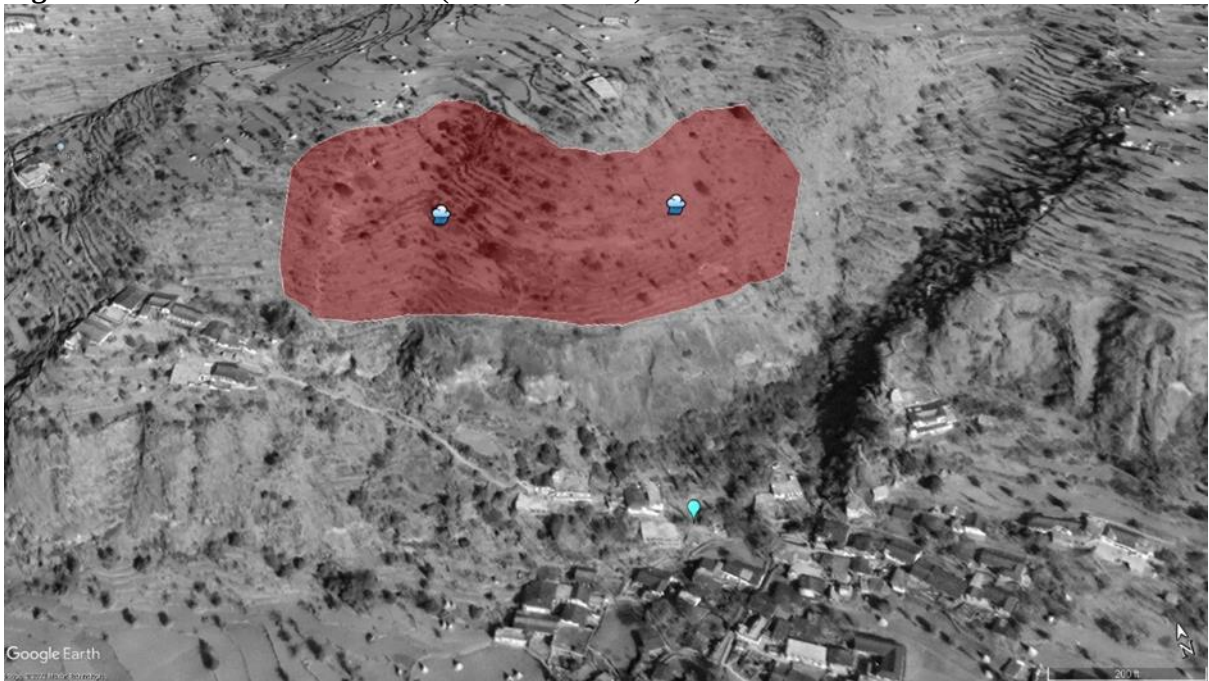


Fig.5.50. The plausible recharge area is demarcated in the red polygon where trenches and pits can be constructed for the rejuvenation of spring RS-233 (marked in the blue balloon).

RS-187 Spring

RS-187 spring is located in Ghera village of Mehal tahsil and about 40 km away from Chamba town towards Chamba-Bharmour highway. Spring is located in the start of the village when approached from main Chamba-Bharmour road. Various characteristics of

the spring is depicted in Table 5.13. Aerial view of the RS-187 spring is depicted in the Fig. 5.51.

Table 5.13. General characteristics of RS-187 spring.

Physiography And Structure	Spring emerges from Eastern facing slope
Location (Lat/Long)	32°27'01.06"N, 76°19' 44.0"E
Elevation (m, amsl)	1388 m
Name of Village	Gehra
Rock Type	Slate with Phyllite Interbands
Land Ownership	Private Land
Land cover	Agriculture & Barren land
Slope (%)	20-40
Slope Aspect	Eastern
Spring Type	Depression
Seasonality	Perennial
Discharge in LPM	7
pH	7.7
TDS (mg/l)	250
Dependence (HHs)	20
Use	Drinking, Domestic



Fig. 5.51. Showing synoptic view of spring RS-187 (marked with blue balloon) and adjoining area (google earth snapshot).

Hydrogeology of RS-187 spring site

The spring RS-187 (Fig 5.51a) is a primary source of water in the Gehra village. The geographic attribute of the spring is 32°27'01.06"N, 76°19' 44.0"E, and is located at the height of 1388 m, amsl. Geologically, the area lies in the Chamba formation of the Vaikrita group. The major litho-types in the area are carbonaceous slate, phyllite, and quartzite. The landuse of the area includes agricultural land and forest land. The rugged topography (with steep slopes) and quaternary debris are the key geomorphological elements of the catchment area. The rocks are mainly exposed along the trails and drainage.

The outcrop of rocks in the vicinity of spring is absent. In contrast, nearby exposures divulge the presence of slates with interbedded phyllites of Chamba formation, the field fabrics viz. foliation, joints, and fractures prominent in the lithounits of the area. During the field visit, it was observed that rocks were majorly dipping moderately in the NE direction while the prominent fracture set was dipping in the SE, S and SW direction. The contact between the debris and strata is also seen (fig. 5. 52b). Since loose soil/debris occupies most of the area and the spring emerges from the topographic low, it is classified as a depression spring.



Fig.5.52. Field photographs a) spring RS-187, b) contact of slate and debris.

Demarcation of recharge area and suggested mitigation measures

Spring RS-187 is central to nearby inhabitants; however, on discussion with stakeholders, it was evident that discharge has decreased in the last decade. The houses are

in the immediate vicinity, which could contribute to the contamination of the source. Spring emerges through a topographic low, and the landuse is majorly agricultural/quaternary deposit in the catchment area. The agricultural land/quaternary deposits act as the sink for meteoric water that facilitates groundwater recharge during the farming seasons.

To demarcate the recharge area of the spring, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. It was evident from the fieldwork that dominant planar structures viz. foliation dip in the NE direction while the fracture set dips in the SE, S and SW direction (Fig. 5.53). Additionally, percolation of the water through the agricultural fields and debris will also affect spring recharge. Given the steep slope in the catchment will hamper the construction of engineering structures for recharge. However, constructing a small check dam in the nearby drainages can help increase the residence time of surface runoff. Thus, considering complex geomorphology and field structural geological data recharge area was demarcated (Fig. 5.54). Subsequently, it is proposed that activities related to rainwater harvesting or other interventions should be endorsed in and around the area demarcated as the recharge area. The cross-section with a conceptual model is also given to appreciate the geological architecture in the vicinity of the spring (Fig. 5.53).

The catchment area includes agricultural fields, drainage, and a steep slope. The presence of agricultural fields and dependence on forest (including grass on slopes) for cattle fodder will require community mobilization for recharge activities. Villagers have been managing this source for ages and are entirely dependent on it during the lean season. The fluctuation in discharge during the peak and lean seasons can be attributed to the variability of the precipitation. Furthermore, nearby households are in proximity, which could increase the contamination. Thus, all the above points should be considered while planning the spring rejuvenation activities in the area. Therefore, it is recommended to go for structures like trenches along the retaining wall and small check dams in the nearby drainages (Fig. 5.54). It will not only recharge the source but also hold the moisture content for the crops.

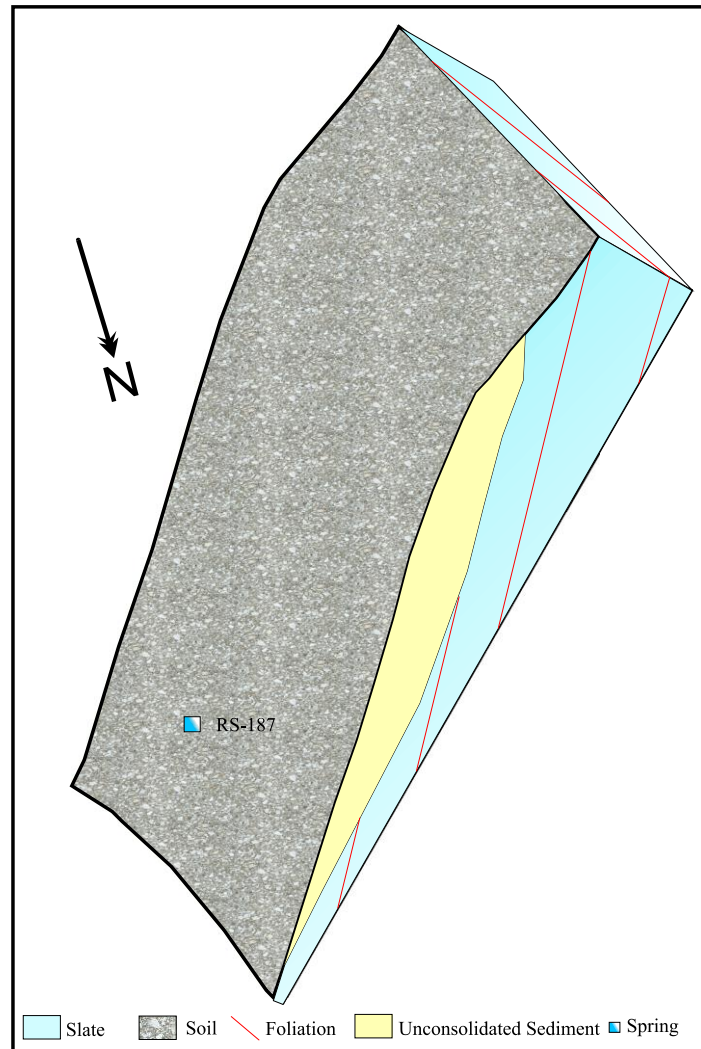


Fig. 5.53. Schematic cross section (not to the scale).

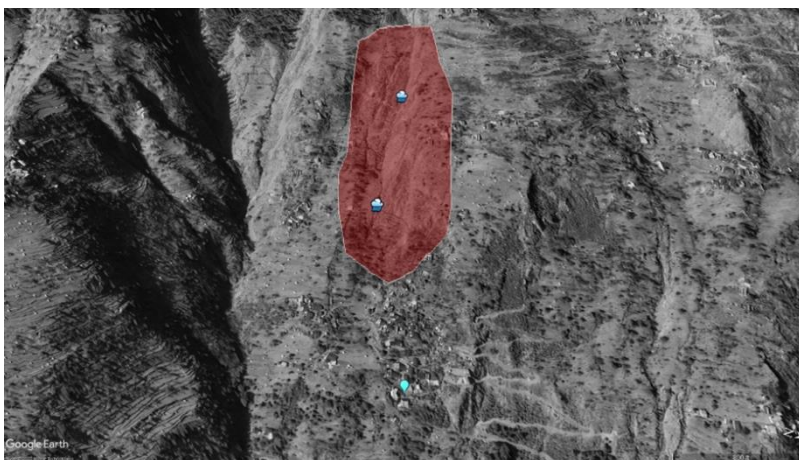


Fig. 5.54. Plausible recharge area is demarcated in the red polygon. The red polygon is the areas where trenches, pits and small check dams can be constructed to rejuvenate the spring RS-187 (marked in the blue balloon).

RS-089 Spring

RS-089 spring (Fig. 5.55) is located in the western side of village Panjesi nad having northan facing. Village is just before 5 km of Bharmour, main halt of the *Manimahesh* pilgrimage. Spring is just below the oak forest which is developed by the villagers as sacred forest (*devsthanam*). The detail characteristics of the spring is given in Table 5.14.

Table 5.14. General characteristics of RS-089 spring.

Physiography And Structure	Spring emerges from South West facing slope
Location (Lat/Long)	32° 26' 56.526" N, 76° 31' 46.182" E
Elevation (m, amsl)	1840 m
Name of Village	Panjesi
Rock Type	Phyllite with slate interbands
Land ownership	Private/Govt. ownership
Land cover	Agriculture land/ Forest
Slope (%)	30-50
Slope Aspect	Northern
Spring Type (as per geology)	Depression cum fracture
Seasonality	Perennial
Discharge (LPM)	8.2
pH	7.9
TDS	277
Dependence (HHs)	75
Use	Drinking, Domestic



Fig. 5.55. Showing synoptic view of spring RS-089 (marked with blue balloon) and adjoining area (google earth snapshot)

Hydrogeology of RS-089 spring site

The spring RS-089 (Fig. 5.55a) is a primary source of water in the Panjesi village. The geographic attribute of the spring is 32° 26' 56.526" N, 76° 31' 46.182" E, and is located at the height of 1840 m amsl. Geologically, the area lies in the Katarigali formation of the Vaikrita group. The major litho-types in the area are slate, phyllite, quartz arenite, limestone, and meta basics (Fig. 5.55b). The landuse of the area includes agricultural land and forest land (Fig 5.56d). The topography with moderate to steep slopes, adjoining drainage, and quaternary debris are the key geomorphological elements of the catchment area. The rocks are mainly exposed along the trails and drainage.

The rocks in the vicinity of the spring are absent. In contrast, nearby exposures divulge the presence of phyllites with slates of Katarigali formation, the field fabrics viz. foliation, joints, and fractures prominent in the lithounits of the area. During the field visit, it was observed that rocks were majorly dipping moderately to low in the NE direction while the prominent fracture set dipped in the NE, NNE, and NW directions (Fig. 5.57). The three springs (Fig. 5.56a &c) in Panjesi village occur linearly, one below the other. Since loose soil/debris occupies most of the area, the spring emerges from the topographic low, and three springs occur linearly (Fig. 5.56d), therefore, RS-089 is classified as a depression cum fracture spring.

Demarcation of recharge area and suggested mitigation measures

Spring RS-089 is central to nearby inhabitants; however, on discussion with stakeholders, it was evident that discharge has decreased in the last decade. The houses are in the immediate vicinity, which could contribute to the contamination of the source. Spring emerges through a topographic low, and the landuse is majorly agricultural/quaternary deposit in the catchment area. The agricultural land/quaternary deposits act as the sink for meteoric water that facilitates groundwater recharge during the farming seasons.

To demarcate the recharge area of the spring RS-089, we have considered different parameters like topographic slope, materials (e.g., debris or bedrock), and the orientation of major and minor planar discontinuities. Apart from the structural conduits percolation of the water through the agricultural fields and debris will also have a bearing on spring recharge. It is noteworthy that at places, the steep slope in the catchment will hamper the



Fig.5. 56. Field photographs a) spring RS-089; b) field photographs of phyllite rock in the catchment; c) another spring (highlighted as green star in fig. 23); d) synoptic view of spring RS-089 catchment with three springs (marked with star of blue, green & red star) occurring in a linear fashion.

construction of recharge structures. Thus, considering complex geomorphology and field structural geological data recharge area was demarcated (Fig. 5.58). The recharge area was extended to facilitate the recharge of the springs in the lower reaches (Fig. 5.56d). Subsequently, it is proposed that activities related to rainwater harvesting or other interventions should be endorsed in and around the area demarcated as the recharge area. The cross-section with a conceptual model is also given to appreciate the geological architecture in the vicinity of the spring (Fig. 5.57).

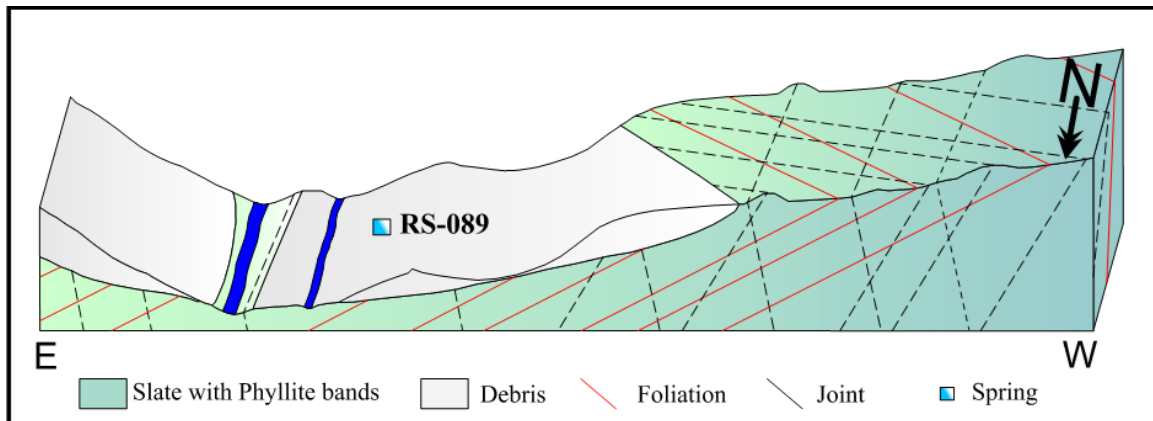


Fig. 5.57. Schematic cross section (not to the scale).

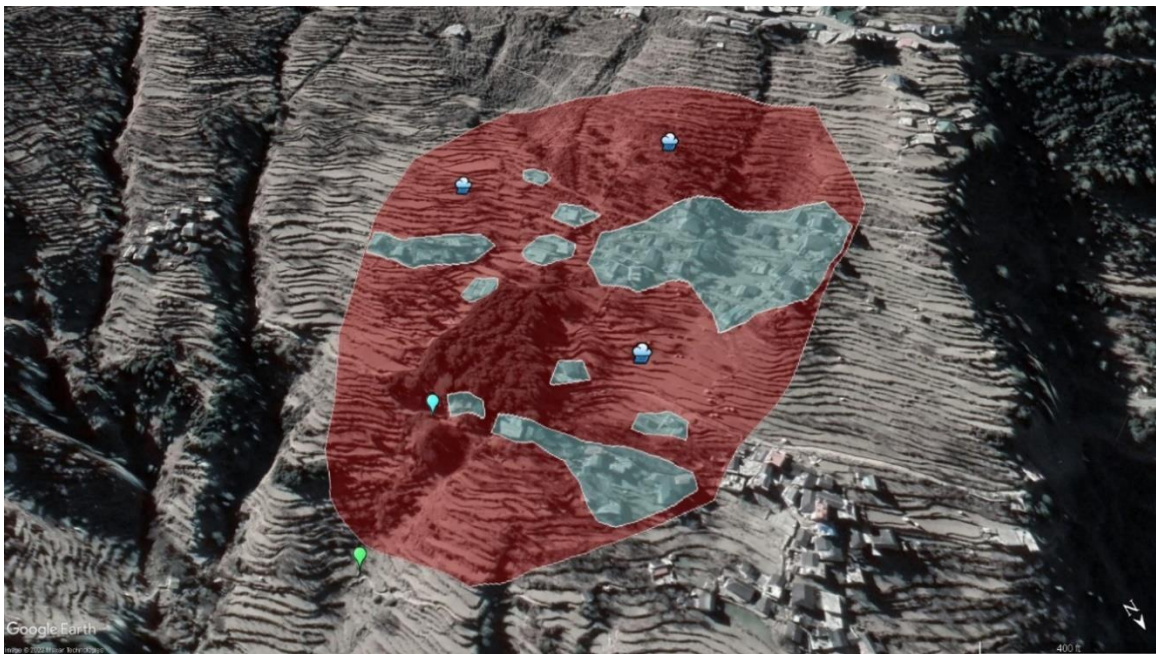


Fig. 5.58. The plausible recharge area is demarcated in the red and blue polygon. The red polygon is the area where trenches and pits can be constructed. A blue polygon demarcates the area where rooftop rainwater harvesting measures can be adopted to rejuvenate the spring RS-089 (marked in the blue balloon). The recharge area was extended to facilitate spring recharge in the lower reaches (spring marked with a green balloon).

The catchment area includes agricultural fields, drainage, and a steep slope. The presence of agricultural fields and dependence on forest (including grass on slopes) for cattle fodder will require community mobilization for recharge activities. Villagers have been managing this source for ages and are entirely dependent on it during the lean season. Furthermore, nearby households could increase contamination. Thus, all the above points

should be considered while planning the spring rejuvenation activities in the area. Therefore, it is recommended to go for structures like trenches and pits, which will not only recharge the source but also hold the moisture content for the crops.

5.7. Capacity Building

The training of project staff and the sharing of project outcomes among the stakeholders were conducted periodically. One training program, titled "*Hydrometeorological Data Collection for Spring Mapping in the Ravi River Catchment*," was held for the field staff of the project as well as the Jal Shakti Vibhag, Himachal Pradesh, on 23-24 March 2018 (Fig. 5.59). Details of the training Programme is given in Annexure-IV.



Fig. 5.59. Training programme conducted at Chamba on dated 23-24 March 2018 for the data collector of project and state government line departments.

Additionally, a one-day stakeholders' workshop on "*Web-GIS-based Spring Information System*" was organized in a virtual format on 02 December, 2020 (Fig. 5.60). This workshop was attended by 91 participants from 51 institutions representing 16 states within the country and 01 overseas. The workshop was graced by esteemed guests, including Sh. U.P. Singh, the then Secretary, Ms. Debashree Mukherjee, Additional Secretary, and Sh. Subodh Yadav, Joint Secretary, DoWR, RD & GR, Ministry of Jal Shakti, Government of India. Details of the training Programme is given in Annexure-V.

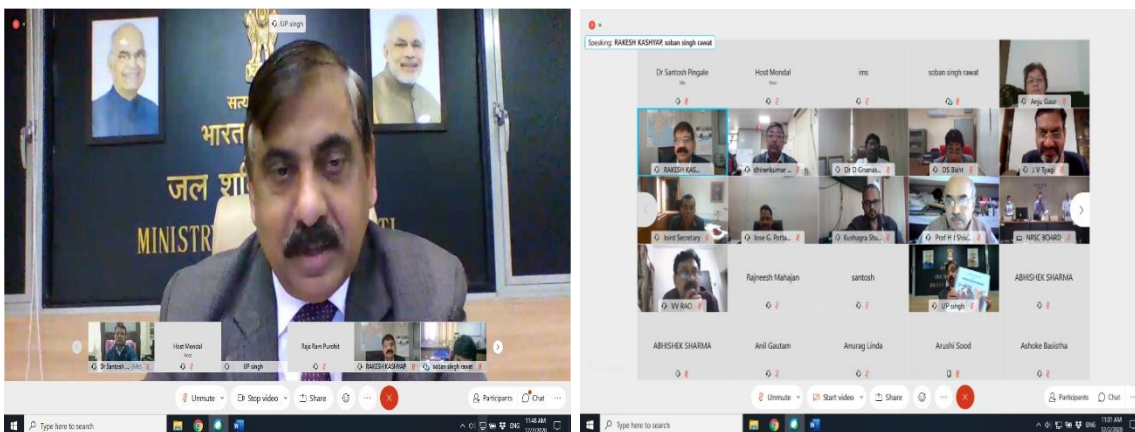


Fig. 5.60. One-day stakeholders' workshop conducted in online mode on 02 December, 2020 in virtual format.

To share the output of the project among the stakeholders a one-day Stakeholder Sensitization Workshop on “Status of Traditional Water Resources (Springs) of Ravi River Catchment” was organized on 20 October, 2023 in the conference room of Govt. Degree College, Chamba, Himachal Pradesh (Fig. 5.61). The objective of the workshop was to sensitize the stakeholders of the springs of Ravi River catchment by sharing the outcomes of the PDS in the form of movie, spring atlas and presentation. On this occasion “Spring Atlas of Ravi River Catchment of Himachal Pradesh was released by the Director, NIH; SE, *Jal Shakti Vibhag*, Chamba; Project officer, Dept. of Rural Development, Chamba; Scientists of CGWB and Krishi Vigran Kendra (KVK), Chamba, Principal and faculties of different departments of Chamba Degree College. In this occasion more than 300 participants from different organizations were presented.

Information regarding the importance of springs in sustaining the water demand, supporting ecosystem and regional biodiversity and the current status of springs in the Ravi catchment area were shared time to time with villagers, local people and school students at various forums (Fig. 5.62).

राष्ट्रीय जल विज्ञान संस्थान रुड़की की ओर से आयोजित कार्यशाला में स्प्रिंग एटलस का किया विमोचन

राजकीय महाविद्यालय चंबा में
सूक्ष्म को राष्ट्रीय जल विज्ञान
संस्थान रुड़की को और से
हितधारक जागरूकता कार्यशाला
का आयोजन किया गया।
कार्यशाला में राष्ट्रीय जल विज्ञान
संस्थान के निदेशक डा. सुधीर
कुमार ने मुख्यार्थिक के तौर पर
उपस्थित दर्शक बरखाई। उन्होंने
सिर्फ एटलस का विमोचन भी
किया। इस कार्यशाला का
आयोजन कमेटी को भूमिका में डा.
मोहिन्द सलारिया, डा. शिवानी
सक्सेना, प्रो. अशोक कुमार, प्रो.
विजय कुमार, प्रो. नील



चंदा। एटलस का विमोचन के दौरान गणमान्य लोग

चौहान रहे। डा. सुधीर कुमार ने जल संसाधनों के सदुपयोग एवं महत्व पर बल देते हुए कहा कि हम सबके सामूहिक प्रयासों से ही आने वाली पीढ़ियों के लिए जल सुरक्षा को सुनिश्चित किया जा सकता है। उन्होंने स्पिंग शोड और जल

उपलब्धता के तकनीकी पहलुओं पर भी विचार सांझा किए। उन्होंने विद्यार्थियों को प्रोत्साहित करते हुए कहा कि कोई भी लक्ष्य नामुकिन नहीं है। कठिन मेहनत से हर लक्ष्य प्राप्त किया जा सकता है। डा. दीपक सिंह विष्ट ने राष्ट्रीय जल विज्ञान

संस्थान रुड़की का संक्षिप्त परिचय एवं संस्थान में चल रहे विभिन्न शोध कार्यों से विद्यार्थियों को अवगत करवाया। प्ररियोजना के प्रधान अन्वेषक डा. सोहन रावत ने सभी के समक्ष पीपीटी के माध्यम से चूबा में राखी जूटी के जल गन्ध

क्षेत्र में मौजूद स्त्रियों के चिह्निकरण एवं पुनर्जीवीकरण की दिशा में किए गए शोध कार्य पर विस्तार से चर्चा की। जल शक्ति विभाग चंबा के अधीक्षण अभियंता राजेश मोंगरा ने जल संरक्षण से जुड़े मुद्दों पर जल शक्ति विभाग द्वारा किए जा रहे कार्य पर प्रकाश डाला।

इस अवसर पर विशेष रूप से केंद्रीय भूमि जल प्राधिकरण के सेवानिवृत्त भू-वैज्ञानिक अरूण कुमार, पौओ डोआडोए चंबा ओम प्रकाश ठाकुर, कृषि विज्ञान विभाग चंबा के वैज्ञानिक डा. केहर सिंह और विभिन्न एनजीओ से आएँ गणमान्य व्यक्ति भी मौजूद रहे।

A large group of students, mostly men, are seated in rows of wooden desks in a lecture hall. They are all looking towards the front of the room, appearing to be listening to a lecture. The students are dressed in casual attire, including sweaters and button-down shirts. The room has high ceilings and large windows in the background.

संघ कॉलेज में राष्ट्रीय जून दिवस समारोह की आयोजकता कार्यवाही के दौरान मौजूद दिखाई।

[illegible]

115



Fig. 5.62. Knowledge sharing field workshop with school students and villagers to disseminate the understanding developed on local springs during the course of the project.

6. CONCLUSIONS AND SCOPE OF FUTURE WORK

Propose Driven Study (PDS) titled “Web GIS Based Spring Inventory for Vulnerability Assessment and Hydro-Geological Investigation of Selected Springs for Sustaining Local Water Demand in Ravi Catchment of Himachal Pradesh” under National Hydrology Project (NHP) is a first kind of study in the country wherein a large number of springs have been studied at catchment scale. The purpose is to integrate these water pygmies with the large size water resources of the region such as river, lake, reservoir, glacier, etc. in gaining the attentions of policy making. NITI Aayog working group report on “Inventory and Revival of Himalayan Springs for water Security” has acknowledged the importance of springs in sustaining the water demand of the Indian Himalayan Region (IHR). However, report also apprised that due to lack of basic data these invaluable water resources could not become the part of our policy. Therefore, development of Web-GIS based spring portal is the first and foremost recommendation of the NITI Aayog report. In this context, this PDS is the compliance of the NITI Aayog recommendation. The report manifested the present status of the springs in the Ravi catchment and it has been found that all springs are either in highly vulnerable or moderately vulnerable condition, which is in alignment with the study of HIMCOSTE, Himachal Pradesh conducted for limited representative gram panchayats of seven districts of the state. In addition to identify the vulnerability, the hydro-geochemical and isotopic studies were also carried out to understand the water quality and recharge mechanism of springs in different seasons. The report can be summarized as:

Chapter 1: Introduction

The introduction sets the stage for the study by providing an overview of the significance of springs in the Ravi River basin. It outlines the objectives of the study, emphasizing the need to understand and address challenges related to spring vulnerability and water resource management.

Chapter 2: Review of Literature

This chapter reviews existing literature on spring studies at international and national levels. It synthesizes key findings and insights from previous research to inform the current study's methodology and analysis.

Chapter 3: Study Area

The study area is described in detail, including its physiography, geological setup, and climate. This chapter provides essential background information to contextualize the subsequent analysis and findings.

Chapter 4: Methodology

The methodology chapter explains the approach taken for data collection, survey execution, field measurements, and analytical procedures. It also describes the development of a Web-GIS based Information System and vulnerability analysis techniques employed in the study.

Chapter 5: Results and Discussions

This chapter presents the results of the study, including spring characterization, vulnerability index, hydrochemistry analysis, seasonal variation of isotopic signatures, and identification of typology and recharge areas for selected vulnerable springs. The findings are discussed in detail, highlighting their implications for water resource management and sustainability.

Spring Characterization:

The study comprehensively characterizes springs in the Ravi River basin, considering factors such as physiography, dependency, uses, ownership, landuse, geological setup, and hydro-chemical properties. Detailed profiles of individual springs provide valuable insights into their unique characteristics and vulnerabilities.

Vulnerability Index and Zonation:

By developing a vulnerability index and zonation map, the study identifies the springs and areas as well which are most susceptible to water resource degradation. This spatial analysis enables targeted interventions and resource allocation to mitigate risks and ensure sustainable management of water resources.

Web-GIS based Information System of Himalayan Springs for Vulnerability Assessment and Rejuvenation (ISHVAR):

The development of a Web-GIS based Information System facilitates data visualization and analysis, empowering stakeholders with valuable information for decision-making. This tool enhances transparency, collaboration, and informed decision-making in water resource management efforts.

Hydrochemistry of Springs in Ravi River Catchment:

Through hydro-chemical analysis, the study elucidates the composition and quality of spring water, identifying potential sources of contamination and assessing overall water quality. These findings are crucial for monitoring water health and implementing measures to safeguard water resources. Additionally spatial maps developed for various water quality parameters using point data are very useful for the implementing agencies to find out the suitable sources of water in the area.

Seasonal Variation of Isotopic Signatures in Precipitation:

The study investigates seasonal variations in isotopic signatures of precipitation, providing insights into recharge mechanisms and hydrological processes. Understanding these dynamics is essential for predicting water availability and managing groundwater resources effectively.

Identification of Typology and Possible Recharge Area of Some Selected Vulnerable Springs:

By identifying typologies and recharge areas for vulnerable springs, the study offers targeted solutions for spring rejuvenation and sustainability. These findings inform the design and implementation of mitigation measures to enhance water availability and quality.

Capacity Building

The capacity-building chapter outlines initiatives aimed at empowering stakeholders with knowledge and skills for sustainable water resource management. It discusses training programs, workshops, and knowledge-sharing activities conducted as part of the study to enhance stakeholder engagement and collaboration.

Each chapter contributes to a comprehensive understanding of springs in the Ravi River basin and provides valuable insights for addressing challenges related to water resource management and sustainability.

Scope of Future Works

The findings and discussions presented in this study provide valuable insights into the complexities of water resource management in the Ravi River basin. However, it is evident that there are still significant challenges and opportunities that warrant further exploration

and action. In light of the results obtained and the discussions held, the following areas emerge as key priorities for future research and intervention:

- There is a need to devise a rejuvenation programme/drive for the identified highly vulnerable springs (231) in the Ravi River catchment. This programme should facilitate coordination between the various state government departments such as Jal Shakti Vibhag, Forest Department, Horticulture, Panchayati Raj, Agricultural, Rural development, Tribal dept. etc.
- The effects of climate change on spring dynamics and water availability are yet to be investigated. In this study, the climate change factors could not be incorporated in the assessment of vulnerability of springs due to the unavailability of long term data series. Further, spring vulnerability needs to be assessed in the context of the livelihood of dependent population by employing Livelihood Vulnerability Index (LVI)-Intergovernmental Panel on Climate Change (IPCC) approach. It will help in assessment of the effect of climate variability on the local water resources and subsequently to develop adaptation strategies to mitigate risks and ensure resilience in the face of changing climatic conditions. In this regard, the role of Himachal Pradesh Council for Science, Technology & Environment (HIMCOSTE), Shimla (H.P.) is immensely important as it has dedicated State Centre on Climate Change (SCCC).
- To develop understanding about the water resource availability and their recharge mechanism, there is a need to conduct detailed hydrological investigations by incorporating stable isotopes like hydrogen and oxygen at regional scale.
- Time to time update of the web-GIS database developed in the PDS will be immensely useful to understand the impact of climate change and anthropogenic activities on spring sustainability. This will help policy makers at large extent to meet the ever-growing water demand with limited water resources available in the form of springs in the mountainous regions.
- Spring survey to be conducted on other parts of the state can be uploaded at the developed Web-GIS database which will be helpful to understand the behaviour of

springs in different agroclimatic and hydrogeological zones of the state and accordingly their treatment and management priorities can be devised.

- Explore opportunities for integrated water resource management approaches that consider the interconnectedness of surface water and groundwater systems. Spring is the part of localized water circulation system wherein rainfall/surface runoff water infiltrate through thin soil layers and moves in the pores and interconnected fractures of the rocks and finally accumulated water manifested on the earth surface where favourable condition occurred. Moreover, spring can act as a system due to which invisible (groundwater) becomes visible (surface water). Therefore, study of springs is needed to consider the factors which affect interconnected system of surface water and groundwater dynamics in the area. SCCC should explore the use of innovative technologies, such as remote sensing, drones, and geospatial modelling and geophysical techniques to improve spring mapping, monitoring, and management. Integrating these technologies into existing frameworks will enhance data collection, analysis, and decision support capabilities of SCCC for providing the inputs to the implementing agencies for rejuvenation of springs in the states.
- Enhance community engagement initiatives to promote participatory approaches in water resource management. Empower local stakeholders with training programs, awareness campaigns, and capacity-building activities to foster community-led conservation efforts. Implement ecosystem restoration and conservation measures to safeguard spring habitats and enhance biodiversity. Collaborate with local communities, conservation organizations, and government agencies to protect critical ecosystems and mitigate threats to spring ecosystems.

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APPENDIX-A Project summary

Table A.1: Summary

Project objectives			
Objectives as per project document		Revised objective	Reasons for revision
➤ Creation of web-enabled database of the springs emerging in the catchment based on extensive inventory of physical and hydro-chemical characteristics. ➤ Mapping of vulnerable springs using hot-spot analysis. ➤ Hydrogeological investigation of some selected springs, which are vulnerable and having high societal importance for identification of their spring-shed area and potential. ➤ To suggest adaptive strategies for selected hot-spot springs for spring sanctuary development to sustain the local water demand. ➤ To build capacity among the local stakeholders through creating para-hydrogeologists for conserving and managing the springs.		Same as Project Document	NA
Manpower deployed (against sanctioned manpower)			
Sanctioned		Deployed	
Designation	Person months	Designation	Person months
JRF (01 N0.)	36	JRF (01 N0.)	40
Field Assistants	159	Field Assistants	159
Infrastructure/ equipment			
Planned (as per project proposal)		Developed/ procured	Reasons for deviation
Ordinary Raingauges (05 nos.)		Ordinary Raingauges (05 nos.)	NA

Establishment of discharge site for spring flow measurement (Tipping bucket flow gauge/civil works)	Establishment of discharge site for spring flow measurement (Tipping bucket flow gauge/civil works)	Site could not establish; data have been collected manually due to COVID 19 interstates restrictions.
GPS (Handheld professional) (04 nos.)	GPS (Handheld professional) (04 nos.)	NA
Hosting and development of information system (Server, domain, web-software etc.)	Hosting and development of information system (Server, domain, web-software etc.) were developed with the help of institute facilities.	NA
High end system (Desktop or laptop)	Not purchased	Desktops and laptops provided by the institute to the PI and Co-PIs were used for the desired purpose of the project.
Portable pH and EC meter (04 sets)	Portable pH and EC meter (04 sets)	NA
Spectrophotometer (UV visible)	Spectrophotometer (UV visible)	NA
Digital burette	Digital burette	NA
Flame photometer	Flame photometer	NA
Water purification system for obtaining Type I water	Water purification system for obtaining Type I water	NA
Field work		
Planned (as per project proposal)	Completed	Reasons for deviation
Extensive survey was planned for identification and mapping of springs	Extensive survey was conducted for identification and mapping of springs	NA
Collection of samples of pre-monsoon and post-monsoon for isotope and chemical analysis of selected vulnerable springs	Pre-monsoon and post-monsoon samples collected for isotope and chemical analysis of six vulnerable springs	NA
Workshop/ Capacity building/ technology transfer		
Planned (as per project proposal)	Organized	Reasons for deviation
Field based training programme (02 nos.)	One field-based training programme and one online workshop were conducted	Due to COVID 19 restriction one field-based training programme was converted in online workshop
Stakeholder's Workshop	Stakeholder Sensitization Workshop	NA

Study area		
Planned	Extended	
Ravi River Catchment up to Chamba (3100 km ²)	Ravi River catchment within the state boundary of Himachal Pradesh (5200 km ²)	
New data generated in the project		
Planned (as per project proposal)	Achievement	Reasons for deviation
Spring inventory (total 981 springs) for Ravi River Catchment up to Chamba (3100 km ²)	Spring inventory for Ravi River catchment within the state boundary of Himachal Pradesh (5200 km ²).	Area increased based on the recommendation of sub-committee of NHP-PDS during 6 th R&D Session.
Water quality data of Springs of Ravi River catchment up to Chamba	Water quality data of Springs (720) of Ravi River catchment within the state boundary of Himachal Pradesh (5200 km ²)	-do-
One year Rainfall data at Five meteorological stations	One year Rainfall data at eight meteorological stations	-do-
One year discharge data of five springs spread over Ravi River catchment up to Chamba	One year discharge data of Eight springs spread over Ravi River catchment falls in Himachal Pradesh	-do-
Envisaged contribution of the project		
Planned (as per project proposal)	Contribution made	Reasons for deviation
There is no extensive database on springs available at catchment scale. The springs which will be mapped as hot-spots by the proposed study will help water resource engineers/researchers to focus their research on those water resources which are having high societal importance. Furthermore, the present study on springs encompasses all major components of the water resource sector under NHP i.e. water resources data acquisition, water resources information systems. The present study is an attempt to provide present status of springs at catchment scale and provide a practical methodology	➤ A well-documented spring inventory with detailed information of 981 geotagged springs was published and supplied to the stakeholders (line depts. and academic institutes) of springs' water in Ravi River catchment. ➤ Web-GIS based ISHVAR portal had been developed and an event on the theme titled “Enabling policymakers in facilitating water security and source sustainability through creation of web GIS enabled inventory of Himalayan Spring” based on this portal was organized in United Nation (UN) workshop COP28 held at Dubai during 30	NA

to develop these springs as sustainable source of regional water supply, and thus, it is likely to be a significant contribution to water sector.	November 2023 to 12 December, 2023. ➤ Highly vulnerable and moderately vulnerable springs have been identified which can be immense useful for the state implementing agencies to fix their priorities for water conservation and rejuvenation activities in the catchment. ➤ Spring Data Collection Format was developed by considering all parameters which are important for springshed management. This Format has been adopted, with some modification, by the Ministry of Jal Shakti for conducting First Spring census of the Country. ➤ A model approach for identification of recharge area of springs have been illustrated in the PDS for six springs spread over the catchment.	
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How research outcome benefited the end user department and society

Planned (as per project proposal)	Benefit derived	Reasons for deviation
As of now, there is no inventory of springs in the Ravi basin, even though springs are the main water sources for about 85% population leaving in the vicinity of the catchment. At the same time, majority of these traditional water resources are in poor condition and continuously drying. It is envisaged that this study may provide present status of the springs of Ravi catchment and identify the vulnerable springs. The adaptive strategies developed under the project for selected vulnerable springs	A scientific database is now available to the end user departments and societies. This database will act as base documents for them to devise the springshed activities in the coming years. Water quality data for the springs spread over the catchment can be useful to understand the spatial extent of groundwater quality in the catchment. This will be helpful to the concerned depts. to identify sites for the safe groundwater sources to meet the local needs. Yield data of various springs can be useful for CGWB to	NA

having high social importance will provide concrete scientific basis to rejuvenate these valuable resources.	understand the extent and capacity of groundwater aquifer system in the catchment. The methodology for identification of recharge area of selected vulnerable springs and use of isotopes to understand the local circulation of water will be helpful to the stakeholders for the effective management of springs at catchment level. Last but not the least the study stressed to study springs at catchment level and the concerned departments can link these water resources with the other available resources for effective integrated water resources management in the Himalayan region.	
End-of-project deliverables		
Planned (as per project proposal)	Achieved	Reasons for deviation
An extensive inventory of the springs emerging in Ravi catchment up to Chamba town of Himachal Pradesh as web database.	An extensive inventory of the springs emerging in Ravi River catchment within the state boundary of Himachal Pradesh as web database.	Area extended by the sub committee during 6 th R&D session
Mapping of vulnerable springs that need urgent preservation in terms of their spring flow quantity as well as quality.	Same as planned	NA
Web GIS based Spring Information System in public domain for public access.	Same as planned	NA
Demarcation of the recharge area of vulnerable springs having high societal importance for effective planning of spring-shed development activities.	Same as planned	NA
Trained manpower or para-hydrogeologists among the local stakeholders that can help to preserve and manage springs.	Same as planned	NA

Outsourcing (>1 lakh)/ consultancy (All)			
Consultant (name and qualifications), organization / outsource agency	Work assigned	Estimated cost (Rs)	Actual cost (Rs)
Dr. Sandeep Bhatt Assistant Professor Dept. of Earth Sciences IIT-Roorkee	• Identification of springs of different typologies. • Geological Survey in the vicinity of the selected springs. • Conceptualizing the hydrogeology of the selected springs for identification of recharge area.	4,35,000/-	4,25,508/-
Financial achievement			

S No	Head	Approved budget	Approved revised budget	Final exp.	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.	2520000	3120000	2931354	Study area was increased from 3100 sq. km to 5200 sq. km based on the recommendation of sub-committee on NHP-PDS in its Sixth R&D session held on 08-09 August, 2019. Besides this, restriction on the movement of interstates during the COVID-19 has also affected the survey work. Therefore, the approval of additional person months was taken in the between of the PDS.
2	Travelling Expenditure	700000	700000	573327	-
3	Infrastructure/Equipment	2345000	1745000	983825	Web-portal was developed by one of the Co-PIs of the project using open-source technology like Geoserver, JavaScript, etc. Laptop and Desktop approved in the original proposal were not purchased as it was given by the institute facility. Discharge was measured manually as discharge site could not established due to restrictions in the interstate's movement during COVID 19.
4	Experimental Charges/Field work/Consumables	300000	300000	346097	-

5	Capacity building/Technology transfer	400000	400000	22369	Workshop was conducted in online mode; hence expenditure was not incurred.
6	Contingency	200000	200000	115862	-
7	Outsourcing/ consultancy	435000	435000	425508	-
	Total	6900000	6900000	5398342	

Table A.2: Quantitative outcome

i. Research papers published/ submitted	
S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/ seminar)
	1. Rawat SS, Gurjar S, Jose PG, Kumar Sudhir, Chenlak Stanzin, Raina G (2019). Inventorization of Natural Water Springs of Ravi River Catchment of Himachal Pradesh. 2nd International conference on “sustainable water management” organized by National Hydrology Project, National Hydrology Project, 6-8 November, Pune, India. 2. Khurana D, Rawat SS, Raina G, Sharma R, Jose P.G (2018) GIS Based Morphometric Analysis and Prioritization of Upper Ravi Catchment, Himachal Pradesh, Advances in Water Resources Engineering and Management. International Conference on “Trends and Recent Advances in Civil Engineering (TRACE 2018). 3. Khurana D, Rawat SS, Raina G, Sharma R, Jose P.G (2018). Book Chapter in “Advances in Water Resources Engineering and Management”. Published by Springer as Lecture notes on civil engineering, ISBN: 978-981-13-8180-5, https://doi.org/10.1007/978-981-13-8181-2 4. Gairola, P., Maiti, A., Sannigrahi, S., Bhatt, A., Singh Rawat, S., Kumar, S., Singh Bisht, D., and Bhatt, S.: A novel approach for predicting spring locations using machine learning algorithms in Indian Himalayan Region, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-13411, https://doi.org/10.5194/egusphere-egu23-13411 , 2023. 5. Rawat S S, Jose P G1, Chenlak Stanzin1, Raina G1, Gurjar Suman2, kumar Sudhir (2022). Inventorization of natural water springs of Ravi River catchment of Himachal Pradesh under purpose driven study of national hydrology project, IWRA (India) Journal, ISSN: 2277-1301. Volume: 11, Issue :1, pp: 33-38

	6. Rawat S S, S P Rai, P G Jose, Suman Gurjar and R V Kale (2017). Inventorization and Adaptive Strategies for Revival of Springs of Ravi River Catchment of Himachal Pradesh for Improved Water Security, 2nd Himachal Pradesh Science Congress (HPSC) 2017-18, Science and Technology for Sustainable Livelihood in Indian Himalayan Region. 7. रावत एस एस, कुमार प्रदीप, गुर्जर सुमन, जोस पी जी, रैना गिरीश, राय एस पी (2019). बदलते मौसम में निरंतर सूखते हिमालयी जल स्रोतों (झरनो) के पुनरुद्धार हेतु वैज्ञानिक समाधान , 6वीं राष्ट्रीय जल संगोष्ठी 16 दिसंबर 2019 से 18 दिसंबर 2019, राष्ट्रीय जलविज्ञान संस्थान, रुड़की. 8. सोबन सिंह रावत, सुमन गुर्जर, दीपक सिंह बिष्ट, सुधीर कुमार, गिरिश रैना एवं द्रोण खुराना (2022). हिमालयी जल स्रोतों के कुशल प्रबंधन एवं पुनरुद्धार के लिए वेब-जीआईएस आधारित सूचना प्रणाली, गोविन्द बल्लभ पंत राष्ट्रीय हिमालय पर्यावरण संस्थान, अल्मोड़ा द्वारा " भारतीय हिमालयी पर्यावरण को प्रभावित करने वाले कारक एवं प्रबंधन" विषय पर दिनांक २८-२९ जुलाई, २०२२ को आयोजित राष्ट्रीय कार्यशाला.
Reports/Monographs/Internal publications brought out	
(i)	Reports/Monographs/Internal publications
	1. Spring Atlas of Ravi River catchment of Himachal Pradesh (2023), Page: 280, Printed by National Institute of Hydrology, Roorkee (Annexure-II) 2. A leaflet titled “Springs of Ravi River Catchment of Himachal Pradesh” 3. Poster on “ISHVAR: A WebGIS-based Spring Information System” prepared for the Exhibition on Himachal Calling held at Solan in sept, 2021. 4. Poster on Springshed Management: NIH’s Diverse Initiatives. 5. Poster on Mountain Spring: Importance, Type & Genesis, Drying Problems and Need for Rejuvenation.
(ii)	New techniques/models/ software/ knowledge developed, if any
	1. A short movie (16:57 minutes) on “Inventorization and revival of Springs of Ravi River basin for sustaining the flow of Ravi River of Himachal Pradesh”. This short movie has been displayed in the 2nd Environment and Climate Working Group Meeting of G20 Summit 2023 to be held at Gandhinagar during 27-29 March, 2023 (https://drive.google.com/file/d/1VISUtKfjDEzRA8cy67OAIWBEVEN8Qg-O/view?usp=drive_link). 2. A short movie (06:50 minutes) Government of India Efforts on Springshed Management. This short movie has been displayed in the side event of United Nation (UN) COP28 conference held at Dubai during 30 November 2023 to 12 December, 2023 (https://drive.google.com/file/d/1py4kiFXb--MLqmhvpvX5sQrdfJRvQrDn/view?usp=drive_link)

(iii)	Web site/ application developed			
Name	Web address	Server location	Launch date	Details of information available
NIH-ISHVAR	http://117.252.14.240:8080/TestSpring@Feb2020/	NIH, Roorkee	02.12.2020 By Hon’ble Secretary DoWR, RD&GR, Ministry of Jal Shakti, GoI	All the information of 981 springs surveyed in the PDS are available
(iv) Patents filed/awarded, if any				
Workshop/ conferences/ seminars/capacity building programmes organized				
S. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)	
1.	Training Course on “Hydro-Meteorological Data Collection for Spring Mapping in Ravi River Catchment under NHP-PDS” at Chamba, Himachal Pradesh.	23-24 March, 2018	Y Annexure-IV	
2.	One-day online Stakeholder Workshop on “WebGIS based Spring Information System”.	02 December, 2020.	Y Annexure-V	
3.	One day workshop on “Status of Traditional Water Resources (Springs) of Ravi River Catchment” organized at Government Degree College, Chamba, Himachal Pradesh.	20 October, 2023	N	
v. Stake holders feedback and action taken on constructive feed back				
Sl. No.	Feedback received	Action taken		
(i)	Various feedbacks, viz., dynamic infographics, report generations, basemap availability, etc. were received during One-day online Stakeholder Workshop on “WebGIS based Spring Information System” held on 02 December, 2020.	NIH-ISHVAR web portal was made more informative and user friendly by developing the webApp and Dashboard in ArcGIS enterprises.		
vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)				
S No	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring/ sea-water	Number (planned)		Numbers (measured)

1.	I. Spring survey i. General information: <i>village, gram panchayat, tehsil, district, latitude, longitude, elevation, Spring type, Nature, Purpose of use, discharge, people perception about discharge, lean and peak month of discharge.</i> ii. Demographic information: <i>dependent villages/household/population/ livestock), level of dependency, land ownership and land use in the vicinity of spring and upstream side.</i> iii. Water quality information (<i>taste colour, odour, pH, EC, TDS, Alkalinity, Iron, Sodium, Calcium, Potassium, Calcium, Magnesium, Carbonate, bicarbonate, Chloride, Fluoride, Nitrate, Sulphate</i>) II. Isotope data i. Rain (one year) ii. Spring Discharge III. Thematic map (DEM, Village, Geotag Spring, Spring vilnerabilityGeology, LULC, Drainage map)	Springs of Ravi River catchment up to Chamba town - - One year One year One each	981 Springs 981 Springs 719 Springs 153 200 One each		
vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.)					
S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
1.	Ordinary Raingauge (08 nos.)	@Rs 2400/set Total Price = Rs 24662	June 2020	100%	NA
viii. Equipment/ software purchased					
a. Equipment purchased					

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
1.	Handheld GPS (Garmin Montana 680)	@ Rs 40500/- piece, 4-piece, Total Rs 191160/-	23.03.2018	100%	-
2.	pH meter (pocket pro, HACH)	@ Rs 8300/- piece, 4-piece, Total Rs 39840/-	10.07.18	100%	-
3.	EC meter (pocket pro, HACH USA)	@ Rs 8835/- piece, 4-piece, Total Rs 42408/-	10.07.18	100%	-
4.	Micro controller-based Flame Photometer with Na, K, Li & Ca filters and compressor Systronica, Model T-28	@ Rs 62100/- piece, 1-unit, Total Rs 65205/-	06.03.2019	100%	-
5.	Motorized Digital Burette, Microlit, Model-TI-50	@ Rs 45000/- piece, 1-unit, Total Rs 47250/-	11.09.2020	100%	-
6.	Spectrophotometer (UV visible), Shimadzu, UV-1900	@ Rs 297000/- piece, 1-unit, Total Rs 311850/-	09.11.2020	100%	-
7.	Water purification system for obtaining Type I water (Bio-Age Equipment, Model-Direct Ultra-TVVF-5)	@ Rs 249000/- piece, 1-unit, Total Rs 261450/-	24.11.2020	100%	-
b. Software purchased					
S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
	NIL				

ix. Plans for utilizing the equipment facilities in future		
S. No.	Installation/ equipment	Planned future use
1.	Instruments enlisted at Sl No. 1-3 (GPS, pH & EC meter)	These will be used in different R&D studies of WHRC, Jammu.
2.	Instruments enlisted at Sl. No. 4-7 (Flame photometer, Digital Burette, Spectrophotometer, Water purification system)	These will be used in different R&D studies of WHRC, Jammu
x. Data dissemination policy for data generated in the project		
1. A “Spring Atlas of Ravi River catchment of Himachal Pradesh” was prepared on the basis of the data collected during the survey of 981 springs in Ravi River catchment. The atlas can be accessed through Digital Repository of NIH. 2. A short video (16:57 minutes) titled “Inventorization and revival of Springs of Ravi River basin for sustaining the flow of Ravi River of Himachal Pradesh” comprising the various activities carried-out under the PDS and the outcome of the project was prepared for sensitizing the stakeholders regarding importance of the project and the approach of the study for replication. 3. A Web-GIS based spring portal (NIH-ISHVAR) was developed to showcase all the collected spring information for easy visualization and understanding. (http://117.252.14.251:8080/TestSpring@Feb2020/)		
xi. Number of post-graduate/doctoral candidates completed their courses (Please give a list of such candidates)		
1. One candidate Ms. Anuradha, Dept. of Environmental Science, University of Jammu, Jammu & Kashmir is pursuing her PhD on “Vulnerability assessment and hydro-geological investigations of selected Himalayan springs for sustaining local water demand in Devika-Birun catchment of Jammu and Kashmir”		
xii. Foreign deputation/visit of PI/Co-PIs/students, if any		
NIL		

A.3 Activity chart

Include activity chart/ modified activity chart, reasons for modification of activity chart.

Modified activity chart is attached as below. Reason for modification is increase of study area on the recommendation of sub-committee on NHP-PDS during its 6th R&D session and restriction of interstate movement due to COVID 19 pandemic.

Activities	Quater																			
	1st year (2018)				2nd year (2019)				3rd year (2020)				4th year (2021)				5th year (2022)			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Recruitment of Project staff																				
Procurement of equipment																				
Conduct survey for identification of springs in the catchment area and collection of water samples for water quality analysis																				
Creation of Web-enabled spring inventory																				
Selection of Spring for detail study and establishment of raingauge and discharge site																				
Meteorological/Hydrological data monitoring and collection of rain and spring waters samples for isotopic and water quality analysis																				
Preparation of Geological map of selected springs																				
Identification of recharge area of the spring																				
Development of adaptive strategy for developing the spring water for sustainable source of water																				
Organizing stakeholder workshop to deliver the project outcome																				
Synthesis of results and report writing																				

Appendix B Supplementary results

Provide supplementary results here, if any.

Excel sheet comprising the details of 981 springs surveyed in Ravi River catchment is given in Annexure-I.

Annexures:

Annexure-I: Spring Inventory (data collected of 981 springs) of Ravi Catchment of Himachal Pradesh
Ravi River catchment.

Annexure-II: Spring Atlas of Ravi River catchment of Himachal Pradesh.

Annexure-III: Vulnerability Index (VI) estimated for 981 springs surveyed in Ravi River catchment.

Annexure-IV: Report of training “*Hydrometeorological Data Collection for Spring Mapping in the Ravi River Catchment*” held at Chamba on 23-24 March, 2018.

Annexure-V: Report of Stakeholders workshop on “Web-GIS based Spring Information System” held in online mode on 02 December, 2020.

*****End of the Report*****