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HYDROLOGICAL INVESTIGATIONS OF SELECTED SPRINGS IN TEHRI-GARHWAL DISTRICT OF UTTARAKHAND

National Institute of Hydrology
Deptt. Of WR, RD & GR,
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Jal Vigyan Bhawan, Roorkee-247 667 (Uttarakhand), INDIA

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PREFACE

Springs are vital sources of freshwater in mountain regions, sustaining communities, ecosystems, and livelihoods. Their conservation and management, however, require a sound understanding of the physical processes, dynamic hydrology, and climatic characteristics of the watershed or springshed in which they occur. Recognizing this need, the present study was undertaken to inventorize, characterize, and evaluate the sustainability of selected springs in the Tehri-Garhwal district of Uttarakhand.

The study employed a comprehensive methodology, combining GIS-based mapping, field surveys, hydrological investigations, and isotopic analyses. A total of 401 springs were identified and digitized from Survey of India toposheets, with detailed inventories prepared for 58 representative springs. Parameters such as discharge, pH, electrical conductivity, and elevation were measured, while water samples were analyzed for chemical and isotopic composition. Two springs Ranichauri and Fakua were selected for in-depth investigation, encompassing hydro-chemical characterization, socio-economic assessment, and evaluation of land use conditions in their respective springsheds/watersheds.

The research further examined the impacts of climate variability and anthropogenic activities on spring flow, using historical precipitation data and statistical trend analyses. Intensity-Duration-Frequency (IDF) curves for rainfall and Flow Duration (FD) curves for spring discharge were developed to aid in climate-smart water resource planning. Findings revealed that while the Ranichauri spring remains relatively balanced, the Fakua spring is severely stressed, necessitating urgent rejuvenation measures.

This study underscores the importance of systematic spring inventory, regular monitoring, and scientifically guided interventions to ensure source sustainability. Recommendations include biological and engineering measures in recharge areas, construction of water harvesting structures, and community-based management strategies. By integrating hydrological science with practical conservation approaches, the study aims to contribute to the long-term sustainability of springs in the Tehri-Garhwal district and beyond.

JV Tyagi
Director

EXECUTIVE SUMMARY

Conservation and management of springs, particularly in the mountain regions, cannot succeed unless one has a basic understanding of the physical and dynamic processes and climatic characteristics of the watershed/springshed. Therefore, this study was undertaken with an objective to inventorize, characterize and evaluate the sustainability of the selected springs in the Tehri-Garhwal district of Uttarakhand.

The methodology adopted for the study included preparation of GIS-based inventory and mapping of available natural springs in the study area and creating a geo-database for the identified springs. Base maps such as DEM, Slope, stream network, etc. were prepared for the study area. Total 401 Springs were identified in the Tehri district and digitized from fifteen SOI toposheets. Further, based on the preliminary field survey, an inventory of about 58 springs was created. Discharge, pH, EC, elevation data were measured and water samples were collected for detailed water quality and isotopic analysis of these springs. Local Meteoric Water Line (LMWL) was established using $\delta^{18}O$ and $\delta^{2}H$ of the identified springs' water. Also, the temporal plot of the isotopic composition of spring water ($\delta^{18}O$ and $\delta^{2}H$) was prepared. From the chemical analysis, it was found that all the spring waters are alkaline in nature (pH: 6.8 to 8.5) with EC ranging from 40 to 1440 µs/cm.

Two Representative springs, viz. Ranichauri and Fakua were selected for detailed hydrological investigations to understand the sustainability of these springs which included hydro-chemical characterization (e.g., discharge, pH, EC), and analysis of physical parameters around the spring's sources. The characterization of the selected springs was carried out using hydrological investigation techniques, and isotopic and chemical characteristics.

The impacts of anthropogenic activities/climate variability on the selected springs were also analyzed. Historical precipitation data of Tehri-Garhwal district were analyzed at different temporal scales. The trends and shifts in precipitation were assessed using Modified Mann-Kendall test and Pettit-Mann-Whitney test. The significant increasing/decreasing trends and shifts in the annual and seasonal rainfall were found, which may be due to anthropogenic activities or climate change effects. Intensity-Duration-Frequency (IDF) curves for rainfall and Flow Duration (FD) curves for the selected springs were constructed. Developed IDF curves can be used in the climate-smart/sustainable design of water resource systems in the springshed/watershed. Also, developed FD curves can be used for the estimation of dependable flows for water availability and distribution planning in the study area.

Study results indicated that Ranichauri hill campus spring is well balanced while Fakua spring is extraordinarily unbalanced and hence needs urgent rejuvenation/catchment treatment measures. The study also indicated that spring flow characterization is necessary to understand the natural water resource potential of the watershed/springshed. The study recommended that there is a need for more efforts on spring inventory preparation and identification of the present status of the springs in the Tehri-Garhwal district. Rejuvenation of the selected springs was recommended to be based on scientific interventions to maintain the source sustainability. Adapting biological and engineering measures in the springs recharge areas (called springshed) was recommended to recharge the springs. Additionally, it was suggested to construct water harvesting structures to store spring water and rainwater to serve as a reservoir to meet the household and domestic needs of the locality during the dry season. Regular monitoring of springs was also recommended. Finally, suitable interventions and scaling out plan was suggested based on hydrological investigations carried out for the study area.

Key Words: *Springs, Isotope, Water Quality, Source Sustainability, Tehri-Garhwal*

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1. INTRODUCTION

1.1 Background

Water is the precious for existence of life of human being and is integral part of all the facets of mountain environment. Hilly areas are facing a serious water availability crisis due to various developmental and economic activities, which results in reduction of protective vegetation cover and forests. This results in poor soil fertility, high sediment yield of rivers and water reservoirs. Due to lack of the protective cover, the infiltration and subsequent recharge to groundwater has declined adversely. Due to meager development of water resources in the mid Himalaya, farmers are mainly dependent on rainfall for agricultural activities, and natural resources like springs, as dependable and sustainable source of water for rural population in remote areas. About 90% of the rural population of this region depends upon natural springs for their water demands. These springs are locally called “Naula” and “Dhara” in Uttarakhand.

Viable sources of water like springs, which are plenty in hills, are drying up because of inadequate recharge of flow domain of springs and there is disturbance in hydrologic cycle of hilly areas. The deforestation, grazing, erosion of top fertile soil, forest fires and developmental activities (e.g. road cutting, mining, building construction, etc.) are the main causes of the spring flow reduction. Most of perennial springs have becomes seasonal, and the seasonal ones have dried-up. With the development of the society the water requirements are growing, whereas, the discharge of natural springs and streams has been diminishing rapidly due to lack of recharge. The difficulty to reach the hilly areas possesses serious limitation on ground observation. Therefore, Field experimentation and information collection to develop planning activities is, therefore, necessary. Almost negligible numbers of springs are being monitored presently for their flow and other hydrological parameters and hence no systematic study has been reported till today for developing these springs as dependable and sustainable sources of water for rural population of especially Himalayan region and particular in Tehri Garhwal region of Uttarakhand.

1.2 Statement of the Problem

The watershed/springshed are dynamic and complex systems involving a range of physical processes (natural or anthropogenic), which may operate simultaneously and have different spatial and temporal influences. Understanding those processes is essential for managing the quality and quantity of water availability from both surface runoff and natural springs flow under changing land use/land cover (LULC) and climatic conditions. The springs form the lifeline for the large part of the population particularly from the most inhabited lesser Himalayan ranges. These natural springs recharge area delineation is essential for protection and management of important spring’s water systems. Protection and management of the springs cannot be conducted unless one has a basic understanding of where the relevant lands are located, infrastructure development for water harvesting. Otherwise, it fails in the extreme events of rainfall, causes stresses during dry season as well as drying of springs due to anthropogenic activities and climatic changes need to be understood for taking adaptive measures.

The accurate information and response of natural springs from different geological settings (i.e., lithological units, hydro-chemical and physiographical units) under variable climatic and LULC change conditions are needed for sustainable development and management of natural springs in the lesser Himalayan watersheds. It is also important to address the various model uncertainties and address it properly in hydrological modeling studies. Keeping in view the above points, there is urgent need to conduct a systematic study on the natural water springs of Tehri Garhwal district of Uttarakhand. The output of the study will be helpful for planning augmentation measures for theses springs and ultimately to rejuvenate the important springs in Tehri Garhwal district (Uttarakhand).

1.3 Objectives

The main objectives envisaged for the present study are as follows:

i) To inventorize, characterize and evaluate the sustainability of the selected springs in Tehri Garhwal district.
ii) To assess the impact of anthropogenic activities/climate variability on hydrologic responses of springs and develop the adaptive measures to sustain the livelihoods.

1.4 Scope of The Study

The present study was undertaken in the Tehri Garhwal district of Uttarakhand with the objective of inventorizing, characterizing, and evaluating the sustainability of natural springs in the mountainous region. The scope encompassed the preparation of a GIS-based inventory and mapping of springs, resulting in the identification of 401 springs across the district from fifteen SOI toposheets. Further, based on the preliminary field survey, an inventory of about 50 springs was created. Discharge, pH, EC, elevation data were measured and water samples were collected for detailed water quality and isotopic analysis of these springs and the detailed characterization of 50 representative springs. Hydrological investigations included measurement of discharge, pH, EC, and elevation, along with water sampling for chemical and isotopic analysis to establish the Local Meteoric Water Line (LMWL) and assess temporal variations in isotopic composition. Two representative springs, Ranichauri and Fakua, were selected for detailed case studies to evaluate sustainability through hydro-chemical, physical, and social parameters, including dependent population, water use, and land use conditions in the springshed. The study further analyzed the impacts of climate variability and anthropogenic activities by examining historical rainfall and spring discharge data, applying statistical trend detection methods, and assessing land use/land cover (LULC) changes. Hydrological tools such as Intensity-Duration-Frequency (IDF) curves for rainfall and Flow Duration (FD) curves for spring discharge were developed to support climate-smart water resource planning. Overall, the scope of the study integrates spring inventory, hydro-chemical and isotopic characterization, climate impact assessment, and sustainability evaluation, while also recommending scientific interventions, water harvesting measures, and regular monitoring to ensure long-term conservation and management of springs in the region.

2. LITERATURE REVIEW

The study of natural springs constitutes a problem of considerable significance, as this forms a major dependable source of available water for drinking and irrigation purposes in hilly areas. However, according to the available literature no detailed integrated hydrological investigations have been done in the area of springs in the study region. In the present study, the available literature on the following aspects was reviewed: (i) Remote sensing and GIS, (ii) natural water springs: geometry and classification of springs, (iii) existing spring flow model, and (iv) spring behavior.

2.1 Remote Sensing and GIS Application

Remote sensing is defined as the science and art of acquiring information (spectral, spatial, and temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation.

Geographic Information System (GIS) is a computer based information system, used to digitally represent and analyze the geographic features present on the Earth' surface and the events (non-spatial attributes linked to the geography under study) that taking place on it. The meaning to represent digitally is to convert analog (smooth line) into a digital form. In other words, GIS is a database system with specific capabilities for spatially referenced data. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. Thus, in essence, GIS can be viewed as an enhanced information system that aids decision-making by referencing data to spatial or geographic coordinates (Sasowsky and Gardner, 1991; Schoolmaster and Marr, 1992).

In India, the major developments have taken place during the last one-decade with significant contribution coming from Department of Space, emphasizing the GIS applications for Natural Resources Management. Notable among them are Natural Resource Information System (NRIS), Integrated Mission for Sustainable Development (IMSD), and Bio-diversity Characterization at National Level. Recently, the commercial organizations in India have realized the importance of GIS for many applications like natural resource management, infrastructure development, facility management, business/market applications etc. and many GIS based projects, according to the user organization requirements.

A certain relationship exists between remote sensing and GIS. The obvious linkage exists in data collection and its subsequent analysis in response to the ‘Pixel’ = “RASTER FORMAT” inherent relationship between remote sensing and GIS. Remote sensing provides thematic spatial information (pixel basis) in Raster format.

GIS platform with Raster and Vector Formal Data Structure (FDS) provides an integration of spatial and numerical attributes. In the present scenario, conjunction of remote sensing and GIS results rational information of sustainable natural resource management. The integration of spatial and non-spatial data sets can often be most appropriately displayed in 3D perspective digital terrain modelling (DTM) to reconstruct the topological/landform changes of the area. Spectrally oriented classification procedures for land mapping include supervised and unsupervised classification.

2.2 Natural springs

A spring is concentrated discharge of groundwater appearing at the ground surface as current of flow water. The main origin of spring water is groundwater, discharged as spring. It is largely recycled water, a part of the hydrologic cycle in which rain on the landfalls, which stored underground, released at surface level and returns to the atmosphere by a variety of means to fall as rain again. Generally, some of this water remains in ground for the use of plants and enters in the ground instead of being held in the soil. It percolates directly to the bedrock layer where it emerges again in a matter of days or weeks as spring. A spring, therefore, issues from the outcrop of an aquifer or where an aquifer is overlain by a pervious alluvial cover. The water of spring may be supplied by free water moving under the control of the water table (water-table spring), by confined water rising under hydraulic pressure (Artesian spring) or by water forced up from moderate or great depths by other forces than hydraulic pressure (geyser, volcanic and thermal springs).

The important factors controlling the location of spring, the direction of movement of effluent water currents and quantity of out flow are as follows: a) Rainfall, b) hydrologic characteristics of the ground surface, c) topography, d) hydrologic characteristics of the water bearing formation, and e) geologic structure. The hydrologic features of spring flow due to the above controls are: a) percolation of free ground water to the surface; b) overflow of ground water reservoirs; c) outflow of subsurface streams; and d) effluent percolation or flow of confined water, including confined water rising under hydraulic pressure and deep water forced upward by other forces than hydraulic pressure. These features in respect to source of spring water may be stated as follows: a) free water table; b) artesian water; c) volcanic water; and d) deep water percolation.

2.2.1 Geometry of springs

Springs are the reflection of ground water resources of a catchment. Spring emerging point is called threshold point and it is also a constant drawdown point till the spring is active. A poor transmissive aquifer produces a few small springs, while thick transmissive aquifer is the origin of large springs. Spring is only a water hole into the earth from a point of overview but actual hydrology of springs is not such as easy. The spring flow domain has been hydrologically decomposed into two domains i) recharge zone; ii) transition zone (Fig. 2.1). The spring's threshold point lies at the end of the transition zone. In the recharge zone, the flow has been assumed to be in vertical direction and in the transition zone, the flow has been assumed to satisfy Dupuit-Forchhemier assumptions.

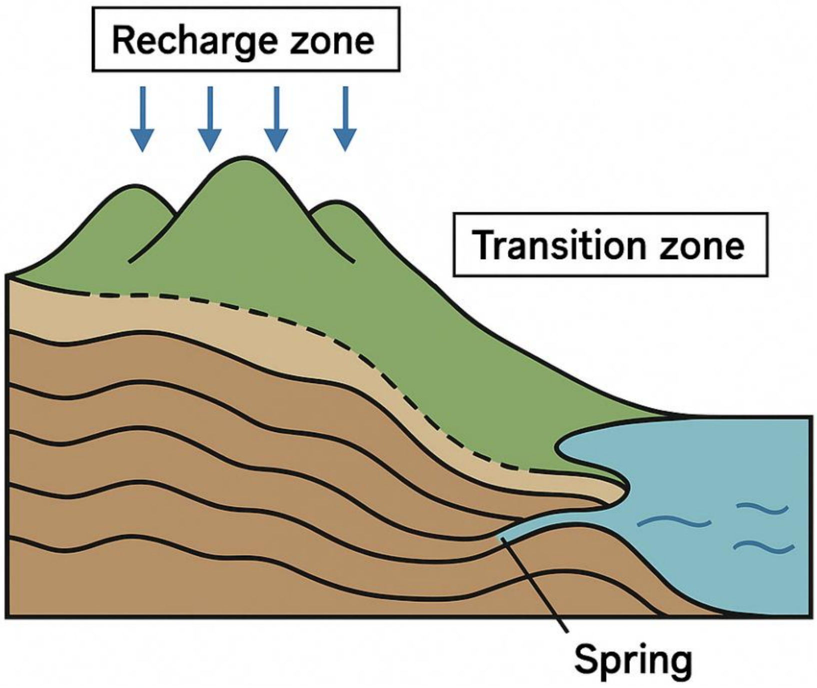


Fig. 2.1. Geometry of a spring.

2.2.2 Classification of springs

Springs occur in many forms and have been classified at to cause, rock structure, discharge, temperature and variability.

i) Classification on the basis of spring flow

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

a) **Gravitational springs-** Springs those resulting from gravitational forces.

b) **Non-gravitational springs-** Springs those resulting from non-gravitational forces. These include volcanic springs, associated with volcanic rocks, and fissure springs, resulting from fractures extending to the great depths in the earth crust. Such springs are usually thermal.

ii) Classification on the basis of geo-hydrological conditions

a) **Depression springs-** These springs discharge where the ground surface intersects the water table. Such springs are generally found in middle and high Himalayan belt.

b) **Contact springs-** These springs are created by a permeable water bearing formation overlying a less permeable formation that intersects the ground surface.

c) **Artesian springs-** Water release from this type of springs is due to under pressure.

d) **Impervious rock springs-** Originated from the fracture of impervious rocks.

iii) Classification on the basis of types of lithologies

It has been observed that lithologies, due to their characteristics and hydraulic parameters (porosity, permeability, storage coefficient) have influence on the recharge behaviour of spring. Perez (1996) classified the flow of spring according to lithology in nine groups:

a) Alluvial sediments; sand and gravels
b) Conglomerates
c) Sandstones
d) Calcarenites, fractured limestones, karstic limestones, dolomites, marbles, tuff
e) Marls, limery marls, silts, clays
f) Quartzites
g) Slates, schists
h) Plutonic rocks, gneisses, dykes
i) Other rocks: gypsum, volcanic rocks

iv) **Classification on the basis of average discharge**

Meinzer (1923) classified the springs according to their mean discharge and this classification has been in use for many years in the United States (Table 2.1).

Table 2.1. Classification of springs on the basis of spring discharge (Meinzer, 1923)

S.N.	Magnitude	Average spring discharge
1	First	>10 m^3/s
2	Second	1-10 m^3/s
3	Third	0.1-1 m^3/s
4	Fourth	10-100 l/s
5	Fifth	1-10 l/s
6	Sixth	0.1-1 l/s
7	Seventh	10-100 ml/s
8	Eighth	< 10 ml/s

v) Classification on the basis of season

a) **Intermittent springs-** Intermittent discharge, only during a part of year, when sufficient groundwater recharge to maintain the flow.
b) **Perennial springs-** Perennial springs drain extensive permeable aquifers and discharge throughout the year.

2.2.3 Spring Behaviour

The available literature related to spring behaviour is reported in this section.

Romani and Singhal (1970) studied the thermal springs of Kulu district of Himachal Pradesh and found from the geological and geochemical evidences that the main source of heat is from magnetic activity manifested on the surface by the tertiary granite, quartz veins and widespread hydrothermal mineralization.

Valdiya and Bartarya (1989) studied the effect of deforestation on diminishing discharge of mountain springs in a part of Kumaun Himalaya. They concluded that the discharge of Gaula river has diminished 29.2 % between 1951-60 and 1961-70 and 38.5 % between 1971 and 1981 due to deforestation. They also noticed the deficiency in rainfall amounting to 9.5 to 76% between 1958 and 1986 in many parts of the study catchment.

Ryon and Meinan (1995) examined the short term variation in water quality at a Karst springs in Kentucky. Runoff from two different subcatchments was tagged with tracer dye and timing of the passage of the resultant dye cloud through big spring and was compared for water quality variations. Distinct lag time between the arrival of direct runoff at big spring and the bacteria and suspended sediment waveforms were shown through the concurrent quantitative tracer tests to be related to the areal distribution of land cover type within the basin.

Angelini and Drugoni (1997) examined the Bagnara spring (Central Italy) fed by a fractured, carbonate and in some areas karstic aquifer. Information was derived from geological mapping and daily flows over a period of 20 consecutive years. There are no data on the hydrological parameters nor on the aquifer hydraulic head, which is known only at the elevation of the spring. The hydraulic conductivity and the specific yield equivalents were estimated by calibrating the model on the master depletion curve and taking into consideration the topographic elevation of the system's surface. The size of the protection area around the spring was investigated on the basis of the isochrones constructed from the results of the model.

Bhar and Mishra (1997) developed a one dimensional spring flow model for time variant recharge by using the Bear model and Duhumel's approach. The model was tested to compute recharge for Kirkgoz springs, a first magnitude karst spring in the Mediterranean region of Turkey. By applying convolution technique, the monthly recharge to a spring flow domain and the depletion time (a model parameter) for a spring were estimated using the Newton-Raphson method.

Perez (1997) proposed a method for the estimation of basin-wide recharge rates using spring flow, precipitation and temperature data in Karstic aquifers by the analysis of hydrograph recession and multiple regression. Recharge (R) can be estimated from precipitation (P) and air temperature by the formula $R = aP - bT + C$. The component a, b and c were derived from time series data of four aquifers in the Mediterranean zone. Given the appropriate correlation coefficients, the procedure is advantageous because of its simplicity.

Desmarais and Rajstaezer (2001) studied of discharge, temperature, conductivity major ion chemistry, and δ^{13} C Variations in a karst spring has revealed a relative single conceptual model of the hydrology controlling the spring's response to precipitation event. The spring's discharge response to precipitation events is very well behaved and repeatable over time. The recession of the spring qualitatively appears to be very diffusional in nature. The chemistry of the spring indicates a patchy connection to the groundwater system.

Hunt (2001) identified the recharge area for a spring complex in Southern Wisconsin using a variety of complementary techniques. A Telescopic Mesh Refinement (TMR) model was constructed from an existing regional scale ground water flow model. A probability distribution of particle captured by the spring, or a 'probabilistic capture zone' was calculated from the realistic Monte Carlo results.

Perez (2001) classified the number of springs in nine litnological groups according to their contribution of flow. These methods have been applied to Spain, a representative region with varied geology, climate and topography; 71.2 per cent of spring flow is supplied by limestones, 19.17 per cent by alluvial sediment and marls, 6.7 per cent conglomerates and sandstones and 3 per cent by slates, plutonic rocks, quartzites and other groups. Springs with discharge rates exceeding 2000 l/s exist only in limestone. The majority of springs with low flow occur in marls.

Rawat *et al.* (2001) identified 73 spring and 27 seepages in Khandagod catchment of Garhwal district. 45 springs were located in Pauri phyllite and rest 28 in Khrisu quartizite formation 40 representative perennial springs were selected for detailed study and it was observed that their occurrence is mainly controlled by bed rock geology and structures. 18 spring were located along the fractured linement, 11 in colluvial deposit, 7 along the joints in colluvian, 3 along bedding contacts and 1 along basic intrusive.

Corraton and Perrochet (2002) derived a one dimensional analytical porosity weighted solution of the dual porosity model and relate exchange and storage coefficients of the volumetric density of the high permeability medium. It is shown that porosity weighted storage and exchange coefficients are needed when handling highly heterogeneous system such as Karstic aquifers using equivalent dual porosity model. The presented 1D dual porosity analytical model is used to reproduces the hydraulic responses of reference 3D karst aquifers, modeled by a discrete single continuum approach.

Amit (2002) developed the recession flow curves having two expontial term with expontial coefficient for nine springs of northern Israel. These coefficients are approximately constant for each spring, refelecting the hydraulic conductivity of different media through which the ground water flows to the spring. The highest coefficient reperstents the fast flow. Probably through cracks, or quickflow, whereas the lower one refelects the slow flow through the porous media. Or baseflow.the compariosion fof recession curves from different springs and different years leads to the conclusion that the main factor that affect the recession curve expontial coifficenmt rae trhe aquifer lithology and the geometry of water conduits therin.

Kristijan Posavec *et al.* (2006) have devloped a visual basic program for an Excel spreadsheet was written to construct a master recession curve (MRC), and applied for to two examples. The first example shows the MRC of an observation well located in an unconfined alluvial aquifer, while the second shows creation of the MRC of a karst sprin. The program uses five different linear/nonlinear regression models to adjust individual recession segments to their proper positions in the MRC.

The program can also be used to analyze the recession segments of other time series, such as daily stream discharge or stage.

Jeelani *et al.* (2011) were analyzed the water samples collected from precipitation, glacier melt, snow melt, glacial lake, streams and karast spring from south–east of Kashmir valley. The time series data on solute chemistry suggest that the hydro-chemical processes controlling the chemistry of the spring waters is more complex than the surface water. This is attributed to more time available for the infiltrating water to interact with the diverse host lithology. Total dissolved solids (TDS), in general, increases with decrease in altitude. However, high TDS of some streams at higher altitudes and low TDS of some springs at lower altitudes indicated contribution of high TDS waters from glacial lakes and low TDS waters from streams, respectively.

Vashisht and Bam (2013) were developed the master recession curves (MRC) for Ranichauri springs located in the mid-Himalayan region of Uttarakhand state for forecasting the discharge rate during the recession period of any year. They have found that the fitting of recession curve by two exponential components yields good results. They concluded that the maximum value of exponential components represents the major contribution to drainage from the spring's catchment's portion with highest permeability, whereas the minimum values represents the major contribution to spring discharge from the portion with lowest permeability. Analysis show that the permeability of the porous medium is responsible for the discharge rate and its capacity is responsible for perennial and seasonal behavior of the springs. The efficiency of formulated master discharge function for Ranichauri spring has been evaluated using the historical spring discharge data and found excellent as Nash-Sutcliffe efficiency was found 0.965.

Saravana Kumar *et al.* (2012) conducted a study of environmental isotopes (^{2}H, ^{18}O, ^{3}H) along with hydrogeochemistry and geomorphology was undertaken to identify the recharge zones of the drying springs. From the stable isotope data of rainwater, altitude effect was estimated (–0.6‰ for $\delta^{18}O$ per 100 m elevation) and recharge zones of the drying springs were identified (+700 to +1150 m msl). Based on the recharge elevations identified from the isotopic study and from the interpretation of the geomorphological setting of the valley and taking into consideration the availability of space, it has been decided that contour-bunding, or building of check dams or levees structures with gabion are suitable methods of rainwater harvesting for augmenting recharge of the drying springs.

Vashisht and Sharma (2013) studied the behaviour of a perennial spring with rainfall variation is analyzed from eight years' data recorded daily. It is concluded that the time required for the water from the remotest part of the feeding catchment of the spring to reach the outlet (time of concentration) is equal to 57 days.

3. STUDY AREA AND DATA USED

3.1 Study Area

The present study was carried out in the Tehri Garhwal district of Uttarakhand, located in the central Himalayan region of India. Tehri Garhwal is characterized by rugged mountainous terrain, steep slopes, and diverse physiographic features that make it a critical zone for spring hydrology. The district lies within the catchment of the Bhagirathi River and its tributaries, forming an important part of the upper Ganga basin. It is surrounded by Rudraprayag District in the east, Dehradun District in the west, Uttarkashi District in the north, and Pauri Garhwal District in the south.

The region experiences a temperate to sub-humid climate, with marked seasonality in rainfall influenced by the southwest monsoon. Annual precipitation varies considerably across elevations, and the variability in rainfall directly affects spring discharge and sustainability. The district is prone to hydro-climatic fluctuations, making springs a vital source of water for domestic, agricultural, and ecological needs.

Geologically, Tehri Garhwal is composed of Himalayan crystalline rocks, schists, and quartzites, which influence groundwater movement and spring emergence. In the district generally, groundwater occurs locally within disconnected bodies under favorable geo-hydrological conditions such as in channel and alluvial terraces of river valleys, joints, fractures and fissures of crystalline and meta-sedimentary rocks, well-vegetated and relatively plain areas of valley portions and in subterranean caverns of limestone and dolomitic limestone country rocks. Groundwater emerges as springs and seepage under favorable physiographic conditions such as in gently sloping areas, broad valleys of rivers and along the lithological contacts (Bagchi and Singh, 2011). The springs are typically fed by subsurface flow through fractured rock formations and soil layers, making them sensitive to both LULC changes and climatic variability.

The district has a population of 618,931 (2011 census). Socio-economically, the population of Tehri Garhwal is heavily dependent on springs for drinking water, household use, and small-scale irrigation. The springs also hold cultural and ecological significance, being integral to rural livelihoods and traditional practices. However, increasing anthropogenic pressures, deforestation, and climate change have led to declining spring discharge in several parts of the district.

For the purpose of this study, springs were inventorized from SOI toposheets of the Tehri Garhwal District and detailed field investigations carried out on representative springs. Further, Ranichauri and Fakua springs were selected for intensive hydrological, hydro-chemical and isotopic characterization to assess source spring water sustainability and understand the impacts of climatic variability. The study area map is presented in Fig. 3.1. The selected springs hold societal importance, and hence, studies on them may contribute to the welfare of the local community.

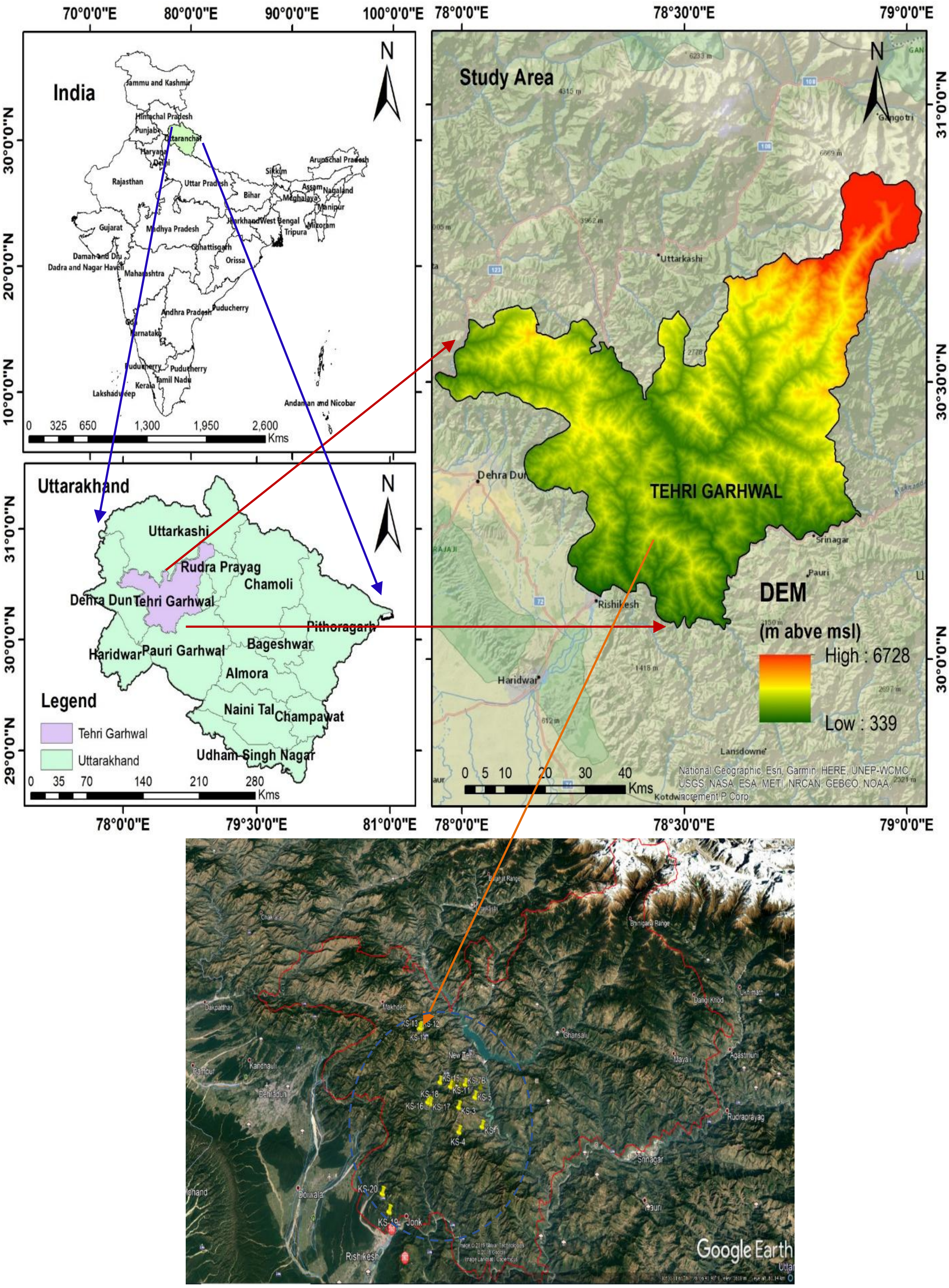


Fig. 3.1. Location of the study area in Tehri Garhwal District

3.2 Data Used

The fifteen SOI toposheets (1:50000 Scale) were used to estimate Springs available in the SOI toposheets in the Tehri Garhwal district. Archival data collection of the historical hydro-climatic data for Ranichauri and Fakua springs were obtained from College of Forestry, Ranichauri. These two perennial springs are being monitored for their spring flow on daily basis. The aquifer (CGWB, India-WRIS, 2019) and lithological formation maps (Soil and land use survey of India, 2019) of Tehri Garhwal district have been used in this study. The gridded daily precipitation datasets (0.25^{o}x0.25^{o}) from 1901 to 2018 was obtained from IMD to identify trends and shifts in the annual and seasonal precipitation in Tehri Garhwal district.

4. METHODOLOGY

The overall methodology adopted in the present study is described here:

i. Preparing comprehensive GIS based spring inventory and mapping of available natural springs in the study area.
ii. Creating geo-database for the springs, which can be updated time to time.
iii. The representative springs from different lithological units selected for physical and hydro-chemical (e.g., discharge, pH, EC, etc.), analysis.
iv. The characterization of spring in different lithological units is carried out using isotopic and chemical characteristics.
v. The trends and shifts in hydro-climatic variables using different statistical techniques (e.g., Modified Mann-Kendall (MMK) test and Pettit's Mann-Whitney (PMW) test) change were carried out for the selected study area.
vi. The characterization and development of Intensity-Duration-Frequency (IDF) curves for rainfall and Flow Duration (FD) curves of the springs flow were carried out using to assess the sustainability of the selected springs.
vii. The impacts of anthropogenic activities/climate variability were assessed within the watershed/springshed and assessed sustainability of the selected springs using reliability index (Q10%/Q90%) (Netopil, 1971).
viii. Finally, suggested adaptive measures to maintain the sustainability of the springs in the study area.

4.1 Measurement and hydro-chemical analysis

A bucket and stop watch were used to take the measurement of spring flow discharge and collected spring water samples for hydro-chemical analysis (Fig.4.1). The springs water samples have been analyzed in the laboratory.

For the analysis of δ^2H and $\delta^{18}O$, 20 ml of water sample was collected in pre cleaned polypropylene bottles (Tarson make). The bottles were rinsed profusely at site with sample water and filled with water samples, tightly capped (to prevent evaporation and exchange with the atmospheric moisture) and brought to the laboratory for isotopic analysis. The selected spring water samples were collected to identify the isotopic signatures of spring water in the study area. On site measurements like sample temperature, pH, EC along with all other relevant site information were also recorded.

The δ^2H and $\delta^{18}O$ isotope measurements were carried out using a Dual Inlet Isotope Ratio Mass Spectrometer (GV instruments, UK) with automatic sample preparation units. For δ^2H and $\delta^{18}O$, 400µL water samples were taken and hook beads were used as catalyst. Along with each batch of samples, secondary standards developed with reference to primary standards (i.e., V-SMOW, SLAP, GISP) were also measured and the final δ-values were calculated using a triple point calibration equation. The overall precision, based on 10 points repeated measurements of each sample, was with the ±0.1‰ for $\delta^{18}O$ and ±1‰ for δD.

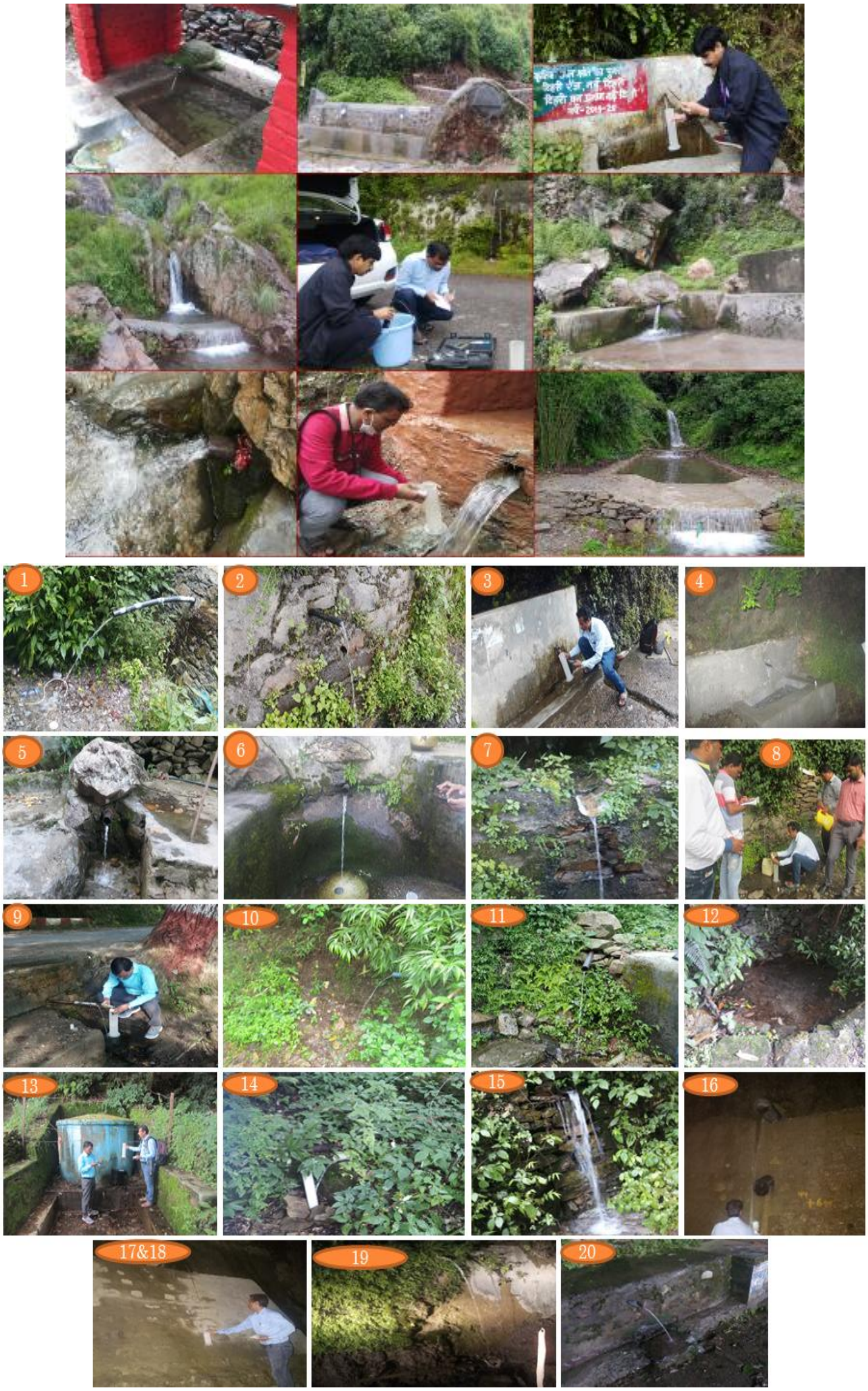


Fig. 4.1. Spring flow measurement and collection of spring water samples for isotopic and water quality analysis in the study area

4.2 Trend and shift detection

The MK test with pre-whitening of time series was used to detect a trend in a time series in the presence of autocorrelation (Cunderlik and Burn 2004). However, pre-whitening reduces the detection rate of significant trends in the MK test (Yue and Hasino 2003). Therefore, the MMK test was employed for trend detection of auto-correlated series (Hamed and Rao 1998; Rao et al. 2003). A significant level of 5% was used for autocorrelation of the rank, which produced the best overall empirical significance level. The advantage of using corrected variance is that there is no need to either normalize data or their autocorrelation function and more details regarding MMK can be found in Rai et al. 2010.

For linear trend present in the time series, true slope is estimated by using a simple non-parametric procedure (Theil 1950; Sen 1968; Pingale, 2014; 2015). The percentage change over a period of time was estimated using Theil and Sen's median slope and mean by assuming a linear trend (Yue and Hashino 2003; Basistha et al. 2009) in a time series (Eqn. 4.1) (Fig.4.2).

$$\%\,change = \left(\frac{Median\,Slope \times length\,of\;\; period}{mean} \right) \tag{4.1}$$

The PMW test was used for the determination of shift in the climatological time series (Pettitt 1979). This test was performed using the evaluation version of Xlstat 2011 software. This test can be briefly described using PMW statistics, which can be found in Kiely et al. 1998; Basistha et al. 2009. A series consisting of probabilities of change point at each year were obtained for shift detection in the time series of annual and seasonal (monsoon and non-monsoon) precipitation.

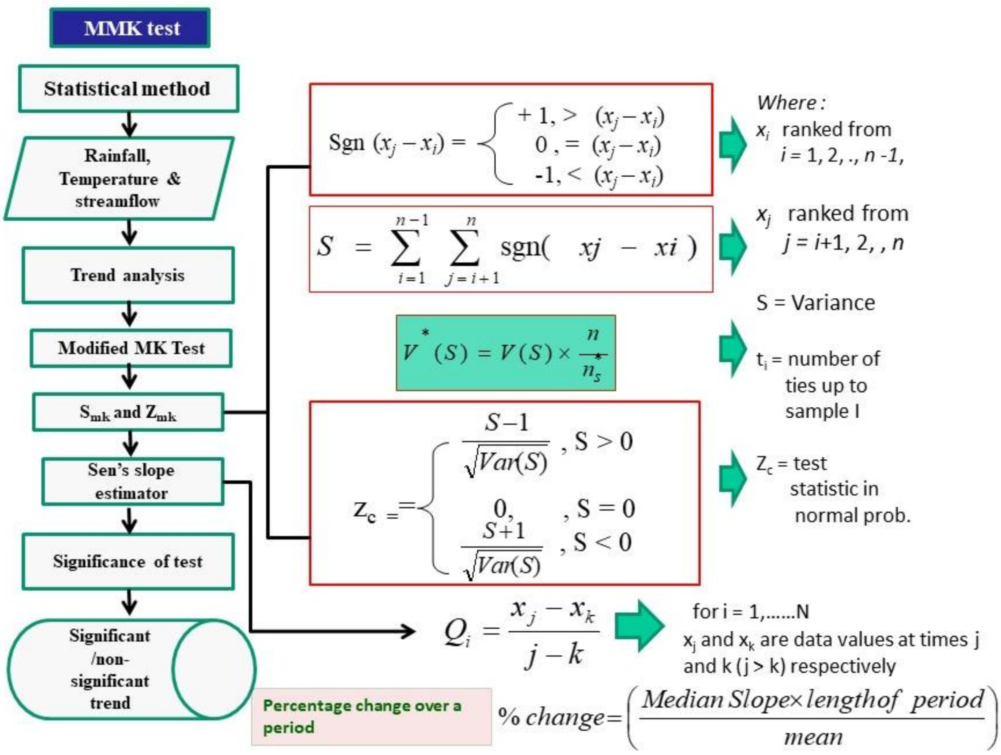


Fig. 4.2. Trend analysis using MMK test

4.3 Derivation of IDF Curves

The IDF curves of the different return periods have been then derived for the study area using different statistical distributions. These includes Gumbel's Extreme Value distribution (GEV), Extreme Value Type-I, Gamma, Exponential and Lognormal distributions (Wikipedia, 2021). These distributions have been applied to the rainfall data of the site and best fit distribution was identified. For example, GEV distribution is described in Eqn. 4.2 and 4.3:

$$x_T = \bar{x} + K_T S \tag{4.2}$$

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \tag{4.3}$$

Where x_T is the average annual daily maximum precipitation, mm; T is the return period, years, $\bar{x}$ is the mean and S is the standard deviation of annual daily maximum precipitation, mm and K_T is the frequency factor for corresponding return period T. Based on the field conditions of the site, suitable return period can be selected for design of the rainwater harvesting structures.

4.4 Flow Duration Curves

Flow duration curves (FDCs) are an effective tool for estimating the variability and reliability of spring discharge over time. They are constructed by ranking observed spring flow data in descending order and plotting discharge values against the percentage of time they are equaled or exceeded. This approach helps in identifying low-flow conditions critical for water supply, medium flows that represent typical availability, and high flows that indicate recharge or peak events. FDCs provide insights into seasonal variability, sustainability of spring discharge, and the resilience of springs to climatic and anthropogenic influences, thereby supporting effective watershed and springshed management.

5. RESULTS AND DISCUSSION

5.1 Springs Inventory

Total 401 Springs were identified in the Tehri Garhwal district digitized from fifteen SOI toposheets (1:50000 Scale) (Fig. 5.1). Further, based on the preliminary field survey, an inventory of about 58 springs was created for the identified springs in the Ranichauri, Gaja, Kanatal, Chamba, Nagini, Narendra Nagar blocks of Tehri-Garhwal district (Fig.5.1 and Fig.5.2).

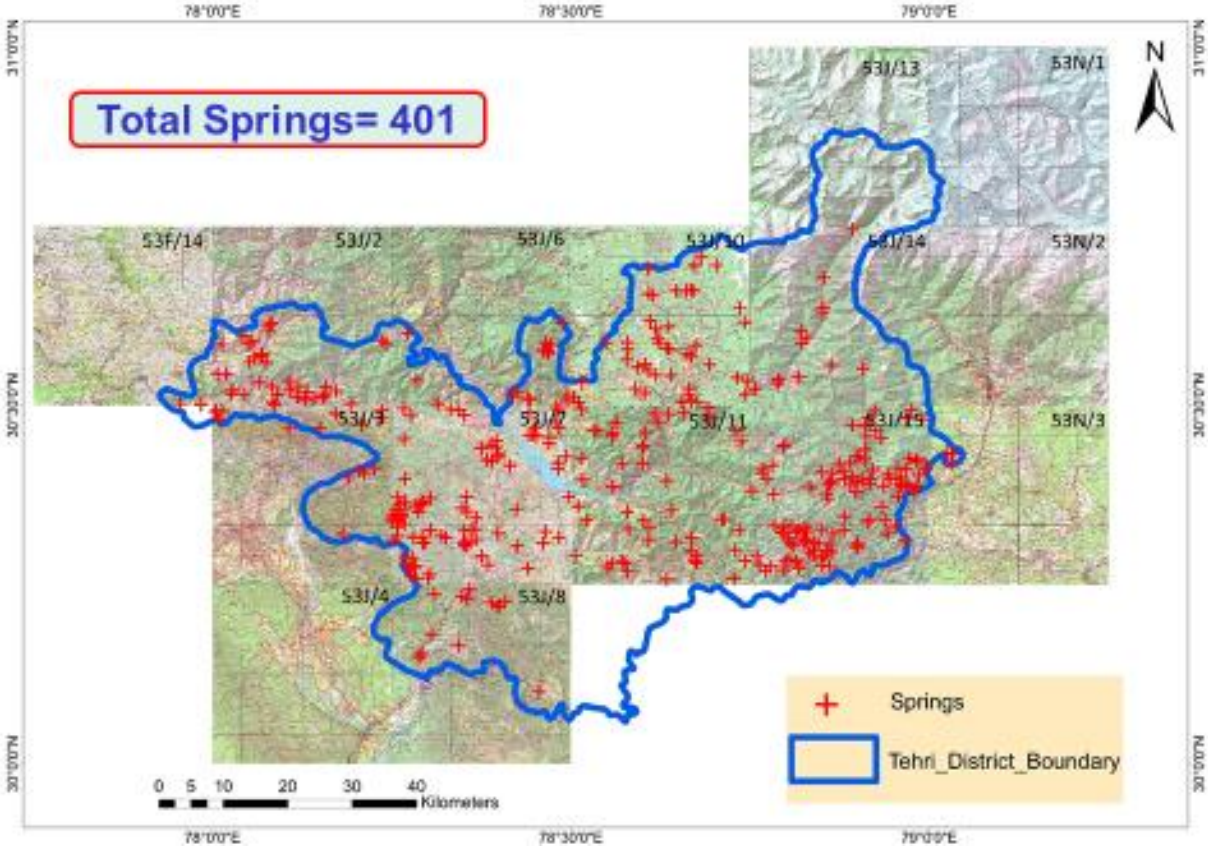
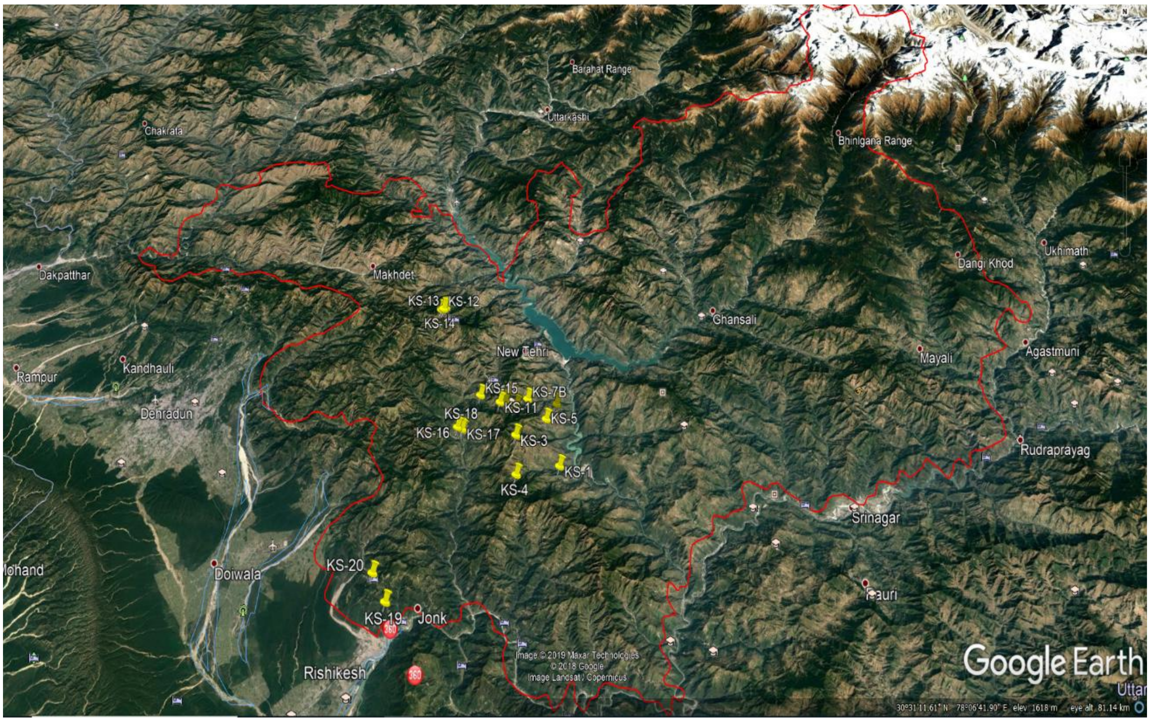


Figure 5.1. Springs identified in the Tehri Garhwal district using SOI Toposheets

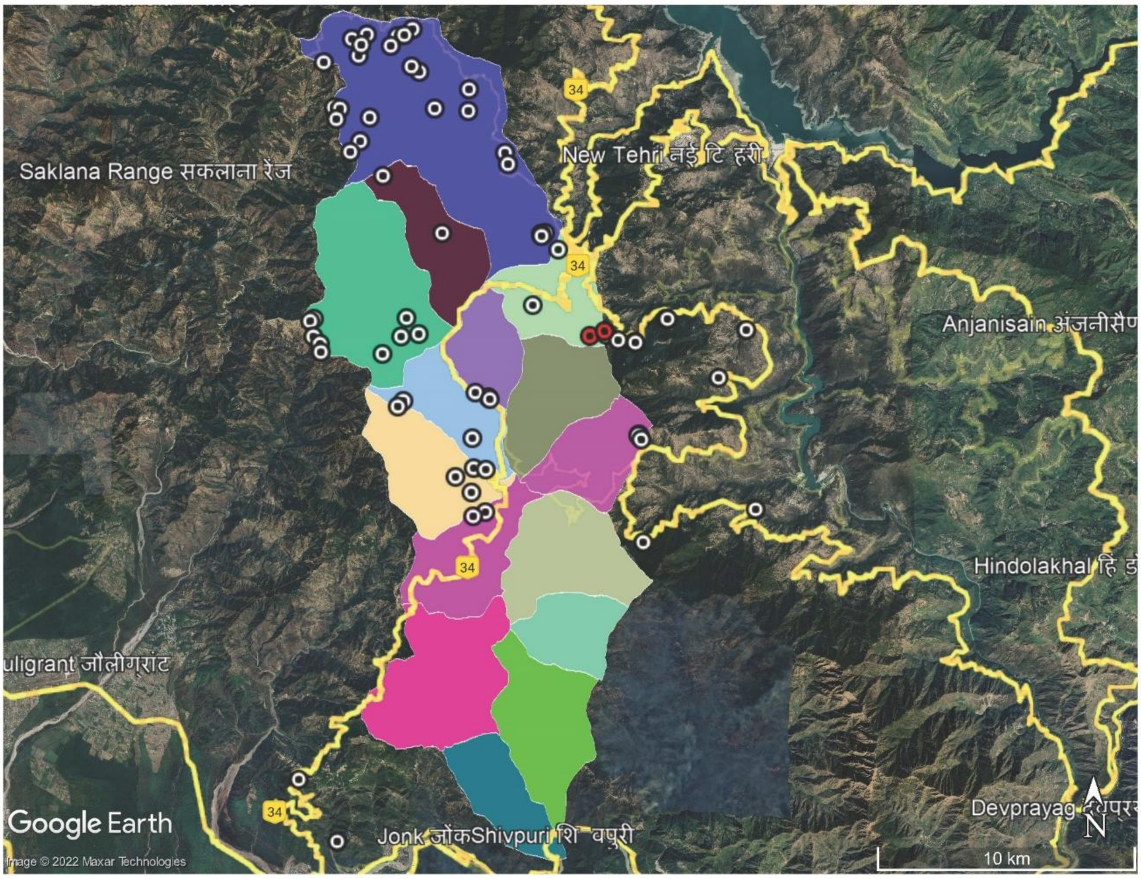
5.2 Physical and hydro-chemical analysis of Springs

The selected springs physical and hydro-chemical characteristics such as pH, EC, geographical location, elevation were measured and collected water samples for detailed water quality and isotopic ($\delta^{18}O$ & $\delta^{2}H$) analysis of the selected springs (Fig.5.2). It was found that all spring water are slightly in alkaline nature (pH ranging 6.8 to 8.5) and EC ranging from 40 to 1440 µs/cm (Fig. 5.3 and Table 5.1). The composition of springwater is dependent on e.g. geological, topographical, meteorological, hydrological and biological factors. It varies with seasonal differences in weather conditions and anthropogenic and LULC activities.



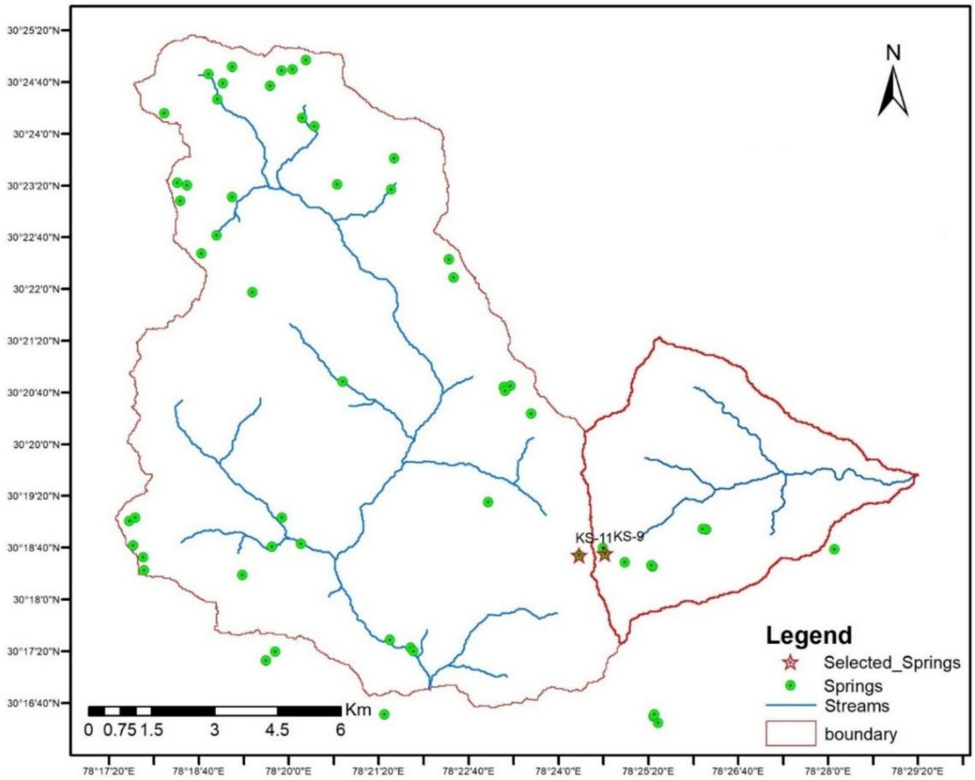
Barahat Range
Uttarkashi
Chakrata
Bhilngana Range
Ukhimath
Dangi Khod
Dakpatthar
Makhdet
KS-13
KS-12
KS-14
New Tehri
Ghansali
Mayali
Agastmuni
Rampur
Kandhauli
Dehradun
KS-15
KS-7B
KS-18
KS-11
KS-5
KS-16
KS-17
KS-3
KS-1
KS-4
Rudraprayag
Srinagar
Doiwala
KS-20
KS-19
Jonk
Rishikesh
Google Earth

(a)



Saklana Range सकलाना रेंज
34
New Tehri नई टि हरी
Anjanisain अंजनीसैण
Hindolakhal
uligrant जौलीग्रांट
Devprayag
Google Earth
Image © 2022 Maxar Technologies
Jonk जोंकShivpuri शि वपुरी
10 km
N

(b)



(c)

Fig. 5.2. Map showing the locations of springs identified in the study area.

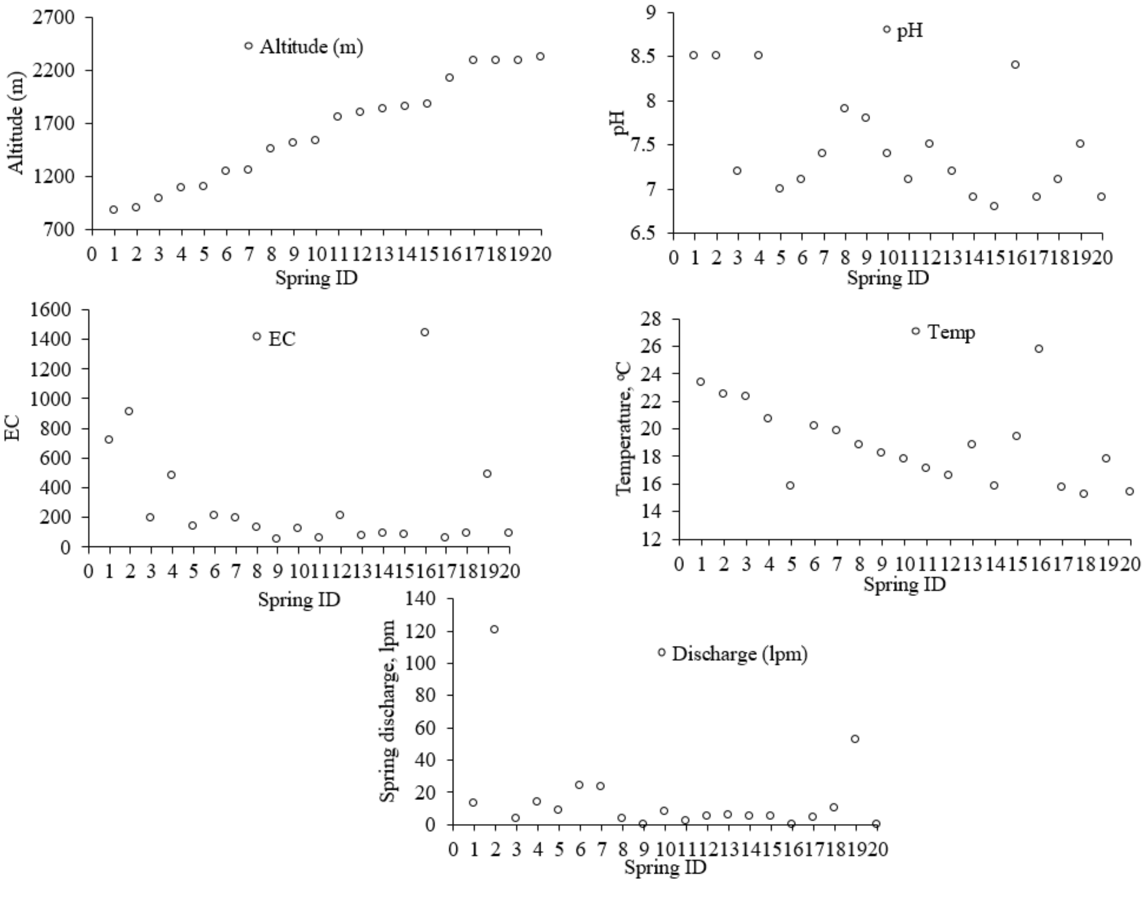


Fig. 5.3. Physiochemical characteristics of springs at different elevation and hydro geomorphological units in various water bearing formations.

Table 5.1. Physio-chemical characteristics of spring's in the study area

Spring ID	Block, District	pH	EC (µS/cm)	Temperature (°C)	Discharge (lpm)	Altitude (m)	Longitude (Degree Decimal)	Latitude (Degree Decimal)	$\delta^{18}O$ (‰)	δD (‰)	H
1	Dhandchilli	7	140	15.8	8.46	1099	78.46507	30.25509	-8.70	-57.78	11.85
2	Dua Koti	6.8	80	19.4	4.89	1879	78.42492	30.26964	-8.71	-58.79	10.88
3	Ghargaon	7.2	70	18.8	5.47	1831	78.42103	30.27072	-8.75	-57.88	12.14
4	Biman Village Gajabhali	7.8	50	18.2	NA	1507	78.42539	30.24096	-8.26	-53.57	12.53
5	Jagethi	7.4	190	19.8	22.81	1250	78.45581	30.29789	-8.83	-62.35	8.30
6	Chhati (Nakot)	7.1	210	20.2	23.53	1244	78.46694	30.31453	-8.99	-60.72	11.22
7	Palli Village, Chamba	7.9	130	18.8	3.09	1455	78.43294	30.31915	-8.43	-57.70	9.77
8	Weer Village, Ranichauri	7.4	120	17.8	8.12	1528	78.42308	30.31858	-8.64	-56.53	12.57
9	Ranichauri Hill Campus	6.9	90	15.8	5.16	1853	78.40777	30.31393	-8.71	-57.26	12.43
10	Downstream of Main Campus, Ranichauri	7.5	210	16.6	5.00	1799	78.41047	30.31392	-8.15	-54.14	11.09
11	Fakua Spring	7.1	60	17.1	1.81	1750	78.40358	30.31233	-8.79	-58.13	12.18
12	Simswani	6.9	90	15.4	NA	2317	78.32893	30.41843	-9.42	-62.56	12.78
13	Near Simswani, Kanatal	6.9	60	15.7	3.98	2286	78.33190	30.41788	-9.47	-61.90	13.82
14	Near Kanatal	7.1	90	15.2	9.76	2289	78.32574	30.41740	-9.38	-63.59	11.48
15	Musani, Choydiyali, Chamba	7.5	490	17.8	52.17	2289	78.37976	30.32175	-8.52	-56.37	11.79
16	Aamsira	8.4	1440	25.7	NA	2123	78.35513	30.28404	-6.95	-47.85	7.72
17	Near Selu Pani (NH-94)	8.5	910	22.5	120.00	894	78.36126	30.29222	-7.43	-50.05	9.35
18		8.5	720	23.3	13.07	882	78.36203	30.29153	-7.30	-49.67	8.70
19		8.5	480	20.7	13.33	1084	78.29332	30.15645	-7.10	-46.61	10.23
20	Narendranagar (Kinwani)	7.2	190	22.3	3.73	991	78.28447	30.15801	-6.61	-44.06	8.78

5.3 Isotopic analysis of springs

Isotopes play a vital role in studying the origin, age, occurrence and distribution of groundwater in a region recharge mechanism, determination of groundwater flow direction and velocity; interconnections and interaction between aquifers; and identification of recharge areas and sources.

5.3.1 $\delta^{18}O$ and δ^2H relationship

The $\delta^{18}O$ and δ^2H relationship of spring water has been developed (Fig.5.4). The regression analysis between $\delta^{18}O$ and δ^2H of the data gives the best fit line (BFL) as:

$$\delta^2H = 6.66 * \delta^{18}O - 32 \quad (n = 21, r^2 = 0.95) \qquad (5.1)$$

where, n is the number of samples and r is the correlation coefficient.

The local meteoric water line (LMWL) thus derived for the study period is (eq.5.1) has slightly less slope as that of global meteoric water line (GMWL) of Craig (1961) which was modified by Rozanski et al. (1993) (eq.5.2) represents average global freshwater composition. The GMWL is developed on the basis of exhaustive isotope data collected through the IAEA/WMO worldwide network. The local and global meteoric water lines are

$$\delta^2D = 6.66 * \delta^{18}O - 32 \qquad (LMWL)$$

$$\delta D = (8.17 \pm 0.1) * \delta^{18}O + (11.27 \pm 0.6) \qquad (GMWL) \qquad (5.2)$$

Meteoric water line is the best-fit line of the $\delta^{18}O$ and δD content of the fresh waters. Craig (1961) after a global survey of stable isotope contents in freshwaters proposed a GMWL, which was later modified by Rozanski et al. (1993). The GMWL is essentially a global average of several LMWL. The LMWL is controlled by the local climatic conditions and the source of the vapour mass, particularly the slope of the line is influenced by the secondary evaporation. The knowledge of LMWL is essential for regional or local hydrological studies.

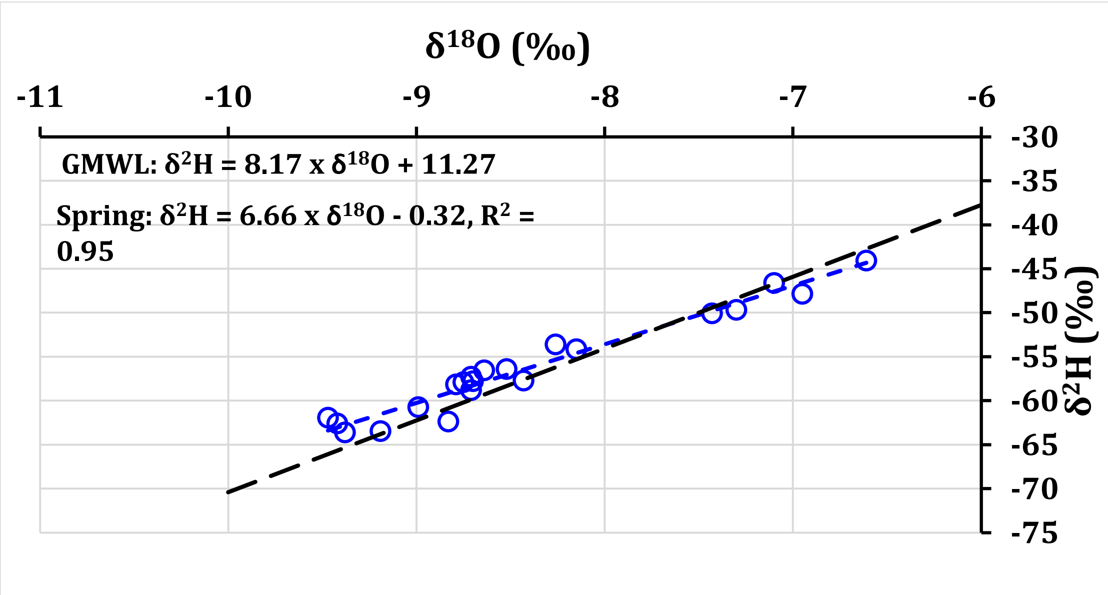


Fig. 5.4. Plot of isotopic composition of different springs water along GMWL

Most of the samples fall below the GMWL and LMWL indicates about the evaporative enrichment of groundwater and spring water in the region (Fig.5.4). The less slope and intercept in comparison of GMWL indicate the evaporative nature of springwater. The major source of springwater in the study area are precipitation. Evaporative nature indicates evaporative fractionation of rainwater in the dry climatic conditions during the recharge process.

5.3.2 d-Excess

The isotopic imprints of evaporation are also recorded in the form of a parameter called d-excess. The d-excess or d-index means the surplus deuterium relative to the Craig's Line. The extent to which $\delta^{18}O$ is more fractionated compared to $\delta^{2}H$ can be defined by Dansgaard (1964) as below:

$$\text{d-excess (d)} = \delta^{2}H - 8 * \delta^{18}O \text{ (‰)} \qquad (5.3)$$

The d-excess (d) as defined above represents the excess $\delta^{2}H$ than 8 times $\delta^{18}O$ for any water body or vapour. The magnitude of equilibrium fractionation (condensation) for $\delta^{2}H$ is about 8 times to that for $\delta^{18}O$. Thus, due to evaporation (non-equilibrium fractionation) from a water body, the D-excess of the evaporating water decreases while it increases in water vapour. The plot of rainwater and groundwater is shown in Fig. 5.5.

The springwater having high d-excess value (i.e., 5‰ to 13‰) indicates less or no fractionation during the recharge. It means groundwater with high d-excess is indicating less or insignificant evaporative enrichment during the recharge process. Low d excess value indicates fractionation of water due to evaporation in the cooling and storage in in the spring water. Most of the spring water shows high evaporative enrichment. The signature of high evaporative enrichment is not visible in the springwater, which indicates that these springs are getting locally recharged through precipitation.

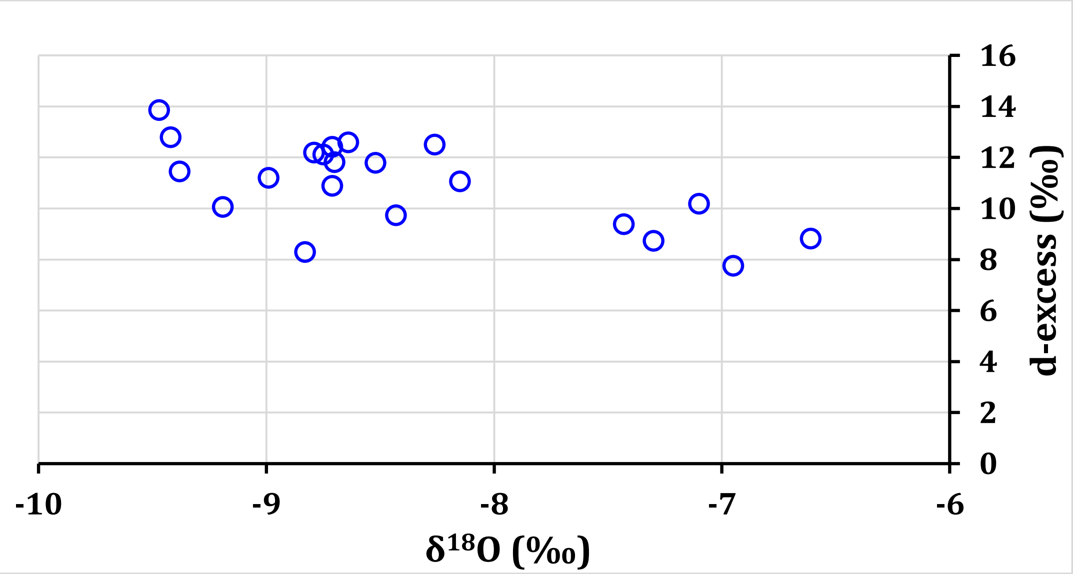


Fig. 5.5. $\delta^{18}O$ - d-excess plot of groundwater

5.4 Hydro-geological investigation of study area

In order to investigate and understand the structural evolution and tectonics of any area or region it is essential to observe and understand the rock deformation and explain how and why the rocks evolved to their present state. Field observations are of paramount importance to achieve this objective, together with experimental studies and modelling. In the present study, aquifer (CGWB, India-WRIS, 2019) and lithological formation maps (Soil and land use survey of India, 2019) of Tehri Garhwal district have been used (Fig. 5.6 and Fig. 5.7) as base maps for detail hydrogeological investigations of the study springs. It has been found that Tehri Garhwal district comes under Schist, Gneiss, Quartzite, Phyllite and Shale with limestone aquifer formations (Fig. 5.8). It is evident that studied springs K19&K20 i.e. SP19&SP20 fall in older alluvium and Pebble/gravel/Bazada/Kandi formation, however other springs (SP1 to SP18) lie in the Phyllite, Quartzite, Shale with limestone, and Schist group.

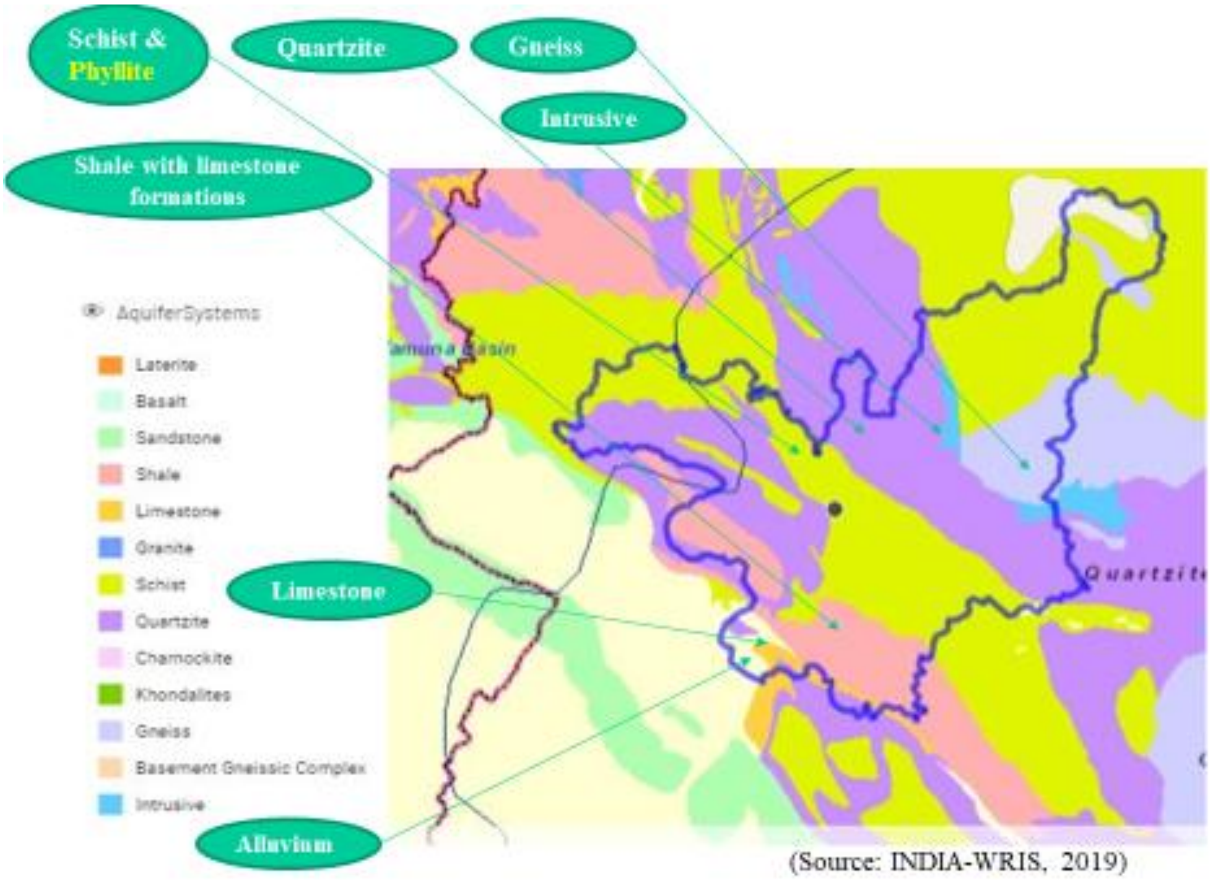
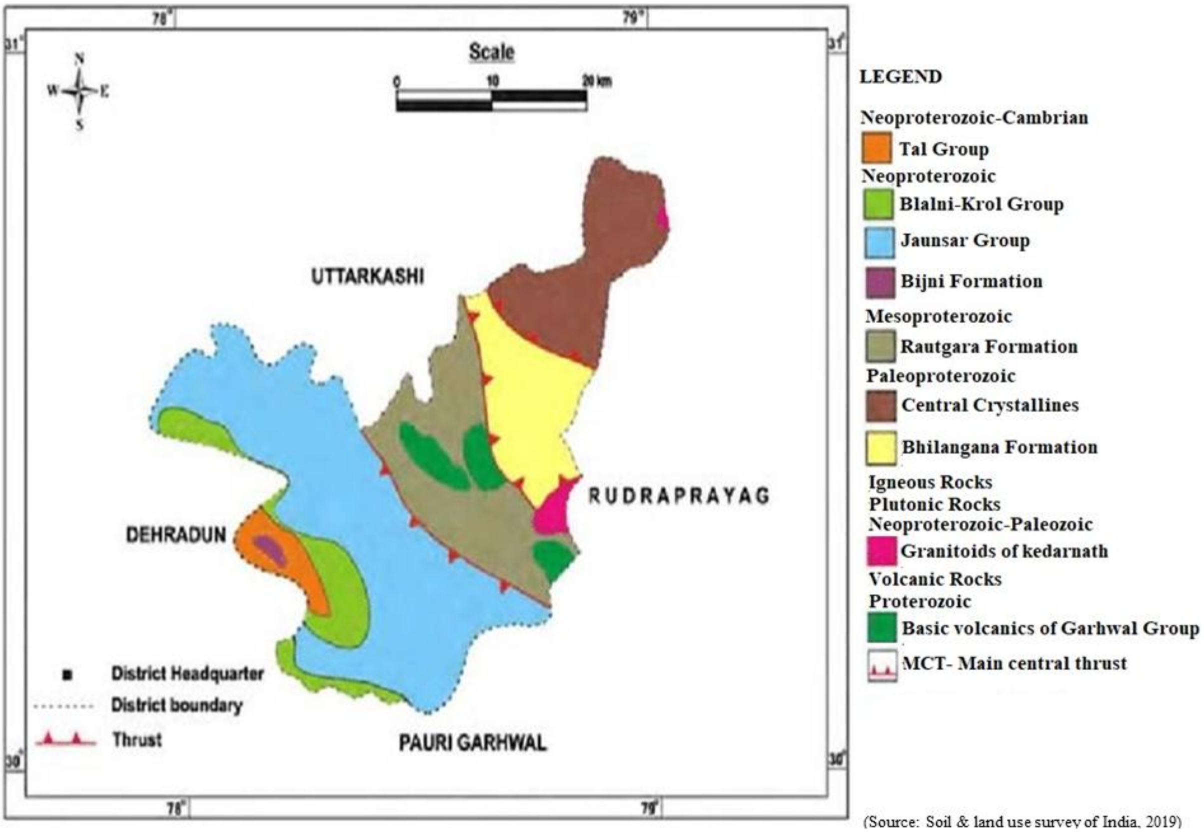
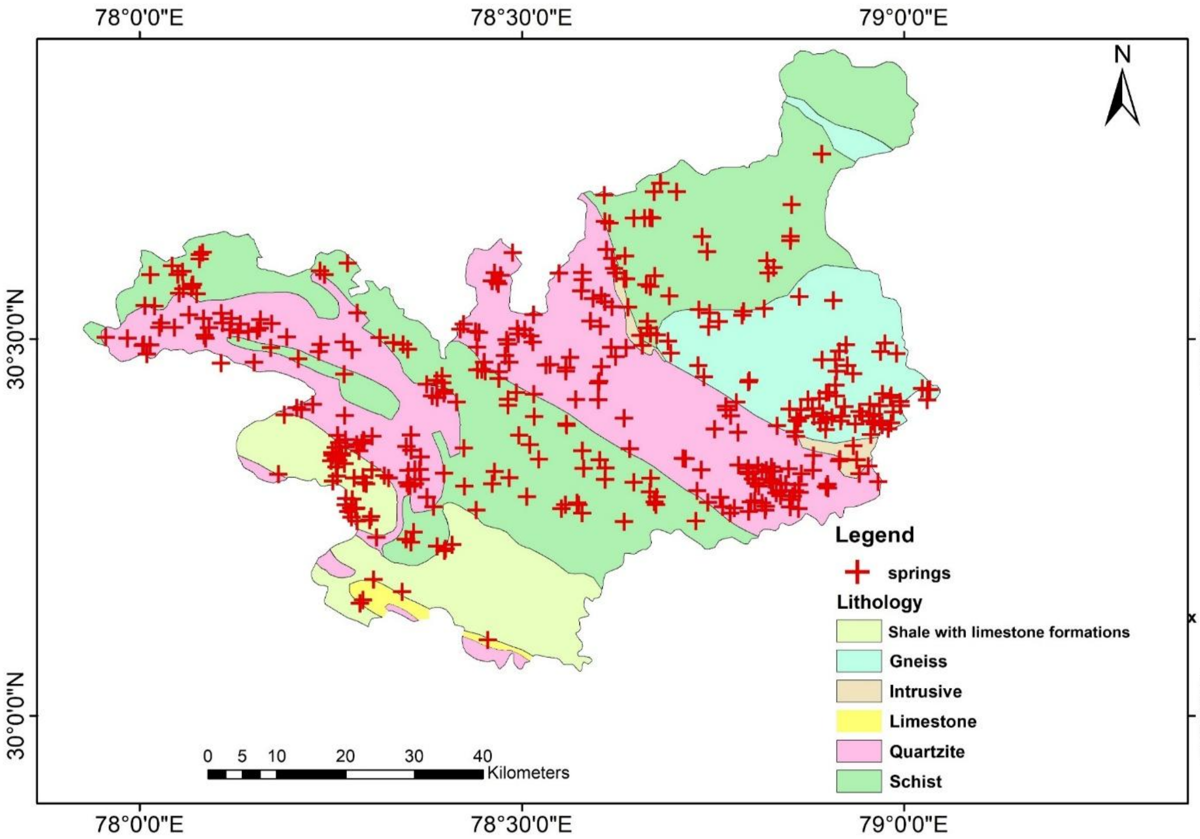


Fig. 5.6. Aquifer system of Tehri Garhwal (Source: India-WRIS, 2019)



(Source: Soil & land use survey of India, 2019)

Fig. 5.7. Lithological formations of Tehri Garhwal district



(Source: Soil & land use survey of India, 2019)

Fig. 5.8. Overlay of springs on aquifer map (Lithology)

5.4 Trend analysis

The trends and shifts in precipitation (IMD grid data 0.5x0.5°) were assessed using MMK test and PMW test over a period of 1901 to 2018. The significant increasing/decreasing trends and shifts in the annual and seasonal precipitation were found at 5% level of significance. This may be occurred due to anthropogenic activities or climate change effects. The detailed trend analysis of seasonal and annual precipitation on trend is presented in Table 5.2 and 5.3, and Fig. 5.9 to 5.12.

Table 5.2. Trends in average annual & seasonal precipitation at 5% level of significance

SN	Grid	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
		Z	Sen's slope	Z	Sen's slope	Z	Sen's slope	Z	Sen's slope	Z	Sen's slope
1	Grid 3	-4.93	-5.22	0.38	0.04	-4.34	-4.70	-1.39	-0.06	-2.68	-0.47
2	Grid 7	-4.28	-6.50	1.30	0.20	-4.14	-6.05	-1.34	-0.07	-2.87	-0.52
3	Grid 8	-6.01	-7.83	*3.19*	0.58	-6.48	-8.12	-1.73	-0.10	-1.13	-0.21
4	Grid 9	-1.55	-1.43	0.17	0.04	-1.30	-0.85	-1.85	-0.08	-1.80	-0.37
5	Grid 12	-7.64	-12.79	*1.85*	0.35	-7.61	-12.37	-1.67	-0.13	-2.73	-0.57
6	Grid 13	-7.28	-12.90	*4.71*	1.00	-7.48	-13.39	-0.94	-0.07	-0.38	-0.09
7	Grid 14	-2.57	-2.28	*2.56*	0.49	-3.13	-2.45	-0.73	-0.04	-0.42	-0.09
8	Grid 20	*3.20*	2.37	*2.96*	0.67	***3.11***	1.83	-0.24	-0.01	-1.11	-0.22

Note: highlighted bold values in green color background indicates significant decreasing trend; Italic values in yellow color background shows significant increasing trend

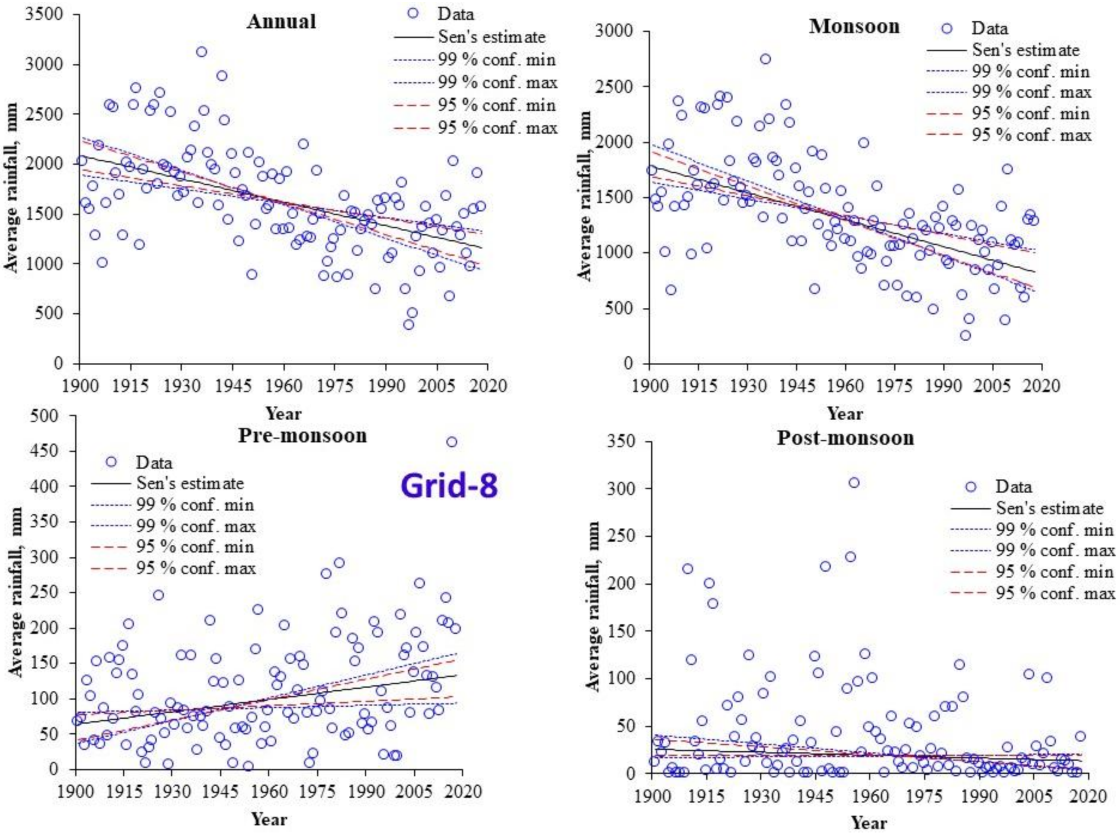


Fig. 5.9. Trends in average annual & seasonal precipitation at 5% level of significance

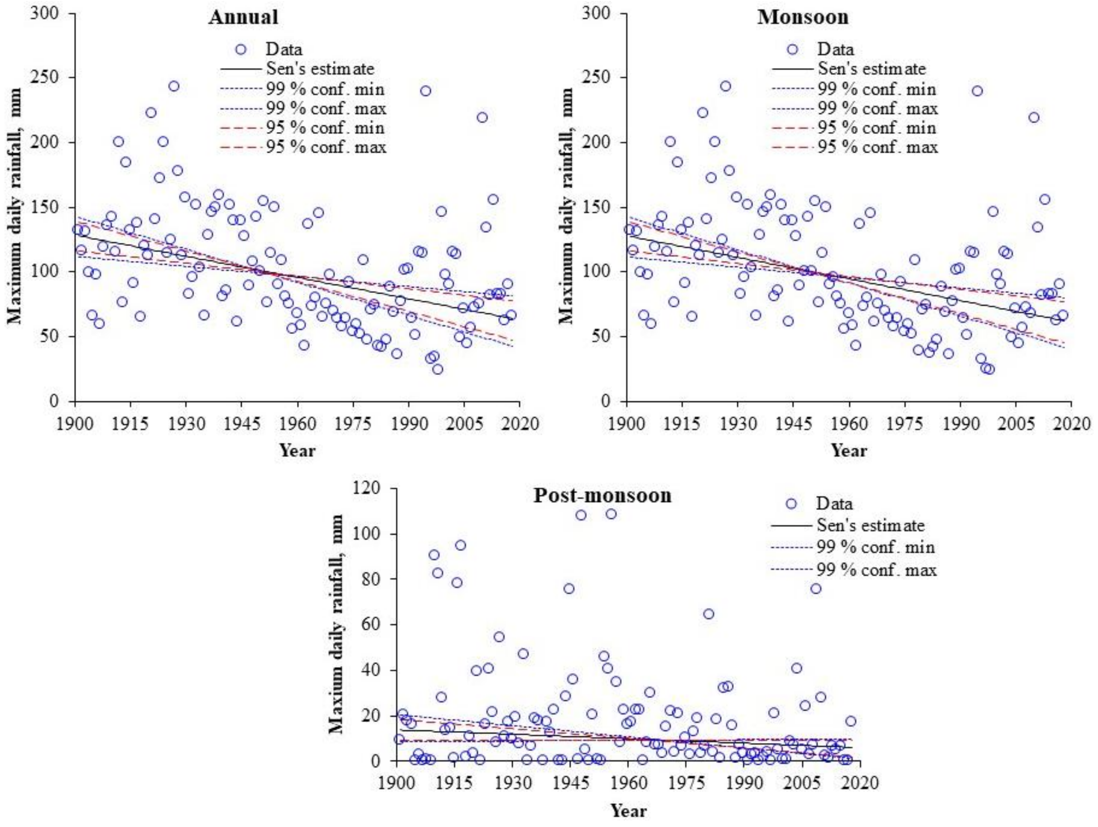


Fig. 5.10. Trends in extreme annual and seasonal average daily precipitation at 5% level of significance

Table 5.3. Trends in extreme annual and seasonal average daily precipitation at 5% level of significance

SN	Grid	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
		Z	Sen's slope	Z	Sen's slope	Z	Sen's slope	Z	Sen's slope	Z	Sen's slope
1	Grid 3	**-1.80**	-0.184	-0.61	-0.018	**-1.75**	-0.179	-1.49	-0.033	**-1.94**	-0.087
2	Grid 7	**-3.32**	-0.415	-0.58	-0.020	**-3.27**	-0.421	**-1.76**	-0.055	**-2.91**	-0.126
3	Grid 8	**-4.73**	-0.548	1.43	0.055	**-4.75**	-0.559	**-2.02**	-0.065	0.10	0.003
4	Grid 9	-1.04	-0.063	-1.22	-0.045	-0.93	-0.048	**-2.17**	-0.044	-0.57	-0.023
5	Grid 12	**-5.65**	-0.661	-0.73	-0.025	**-5.65**	-0.675	**-2.27**	-0.088	**-3.03**	-0.128
6	Grid 13	**-4.93**	-0.640	***3.12***	0.118	**-5.14**	-0.667	**-1.69**	-0.067	0.55	0.025
7	Grid 14	-0.95	-0.058	0.46	0.017	-0.79	-0.049	-1.27	-0.036	0.90	0.030
8	Grid 20	0.37	0.020	1.54	0.055	0.25	0.016	-0.21	-0.006	1.18	0.040

Note: highlighted bold values in green color background indicates significant decreasing trend; Italic values in yellow color background shows significant increasing trend

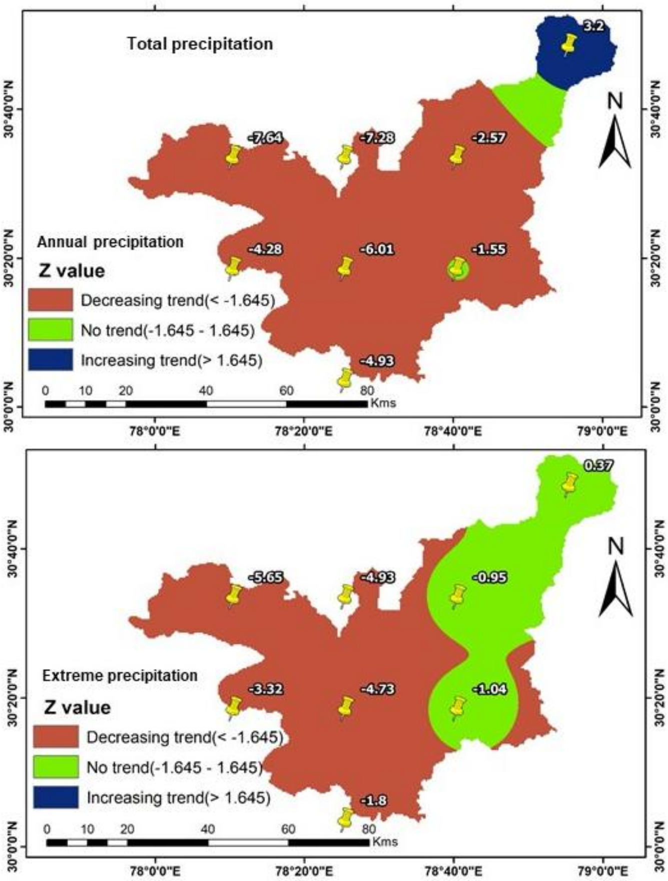


Fig. 5.11. Trends in annual and extreme average daily precipitation in the Tehri Garhwal

Table 5.4. Shift in average and extreme annual and seasonal precipitation

SN	Grid	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
		Total	Extreme	Total	Extreme	Total	Extreme	Total	Extreme	Total	Extreme
1	Grid 3	1970-1971	*	*	*	1970-1971	*	*	*	1962-1963	*
2	Grid 7	1966-1967	1966-1967	*	*	1966-1967	1966-1967	*	*	1962-1963	1968-1969
3	Grid 8	1957-1958	1956-1957	**1961-1962#**	*	1954-1955	1954-1955	*	*	*	*
4	Grid 9	*	*	*	*	*	*	*	*	*	*
5	Grid 12	1967-1968	1969-1970	*	*	1967-1968	1969-1970	*	1987-1988	1943-1944	1946-1947
6	Grid 13	1957-1958	1957-1958	**1955-1956#**	**1977-1978#**	1954-1955	1954-1955	*	*	*	*
7	Grid 14	1957-1958	*	**1976-1977#**	*	1953-1954	*	*	*	*	*
8	Grid 20	**1954-1955#**	*	**1976-1977#**	**1985-1986#**	**1956-1957#**	*	*	*	*	*

Note: * denote shift have not been observed in precipitation during 1901–2018; # indicates **positive shift** & rest negative shift

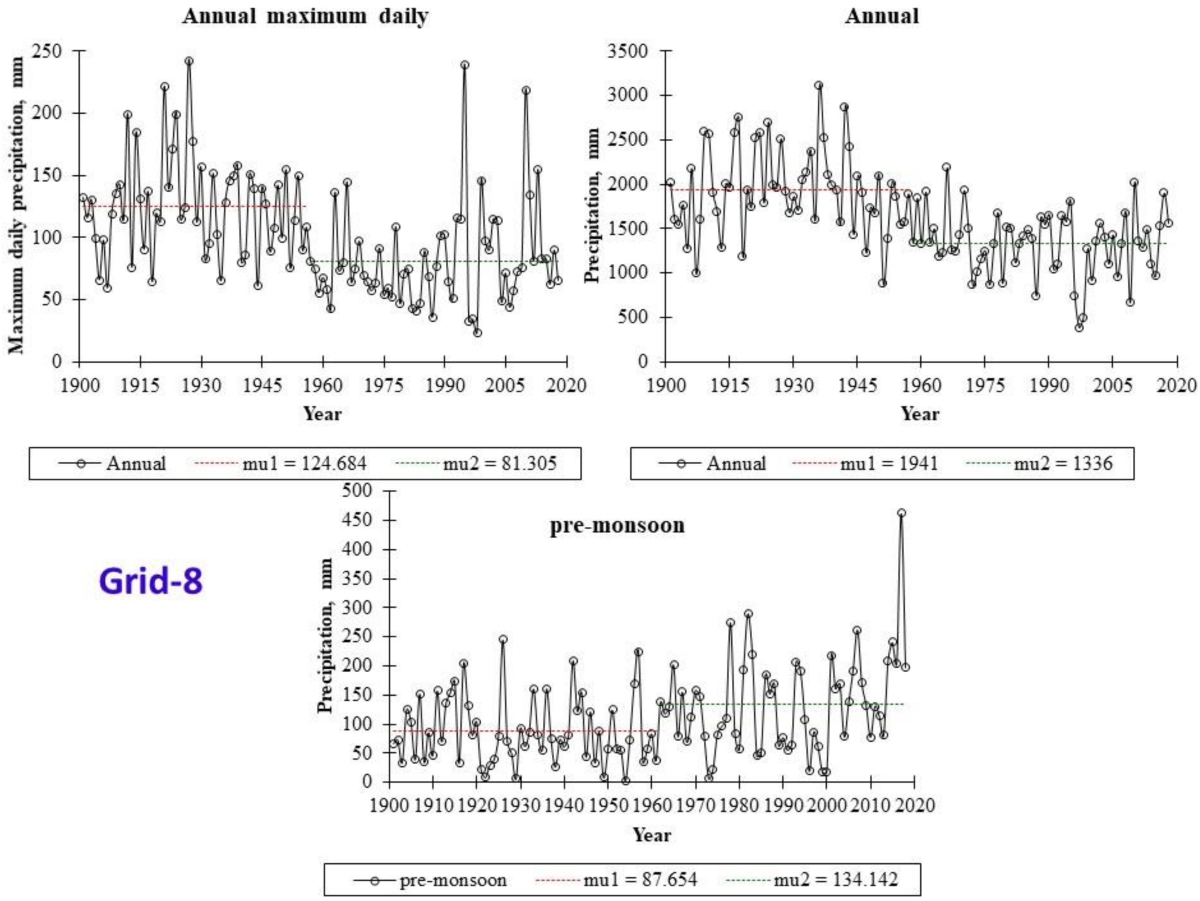


Fig. 5.12. Shift in average and extreme annual and seasonal precipitation

5.5 Intensity-Duration-Frequency (IDF) Curves

An IDF curve is a mathematical function that relates the rainfall intensity with its duration and frequency of occurrence. These curves are derived from best fit IDF curves based on Gumbel's EV-I, Gamma, Log Pearson Type-III, Normal & Log-Normal distribution. These curves are commonly used in hydrology for assessing rainfall events, classifying climatic regimes, to deriving design storms and assisting in designing drainage systems, etc. The deriving procedure of IDF curves, however, requires long-term historical rainfall observations, whereas lack of fine-timescale rainfall records (e.g., sub-daily) often results in less reliable IDF curves. The IDF curve parameters have been computed for different duration of storms of different return periods from IMD rainfall gridded dataset (Fig. 5.13). Based on field conditions, suitable return period with rainfall intensity can be selected for design of the rainwater harvesting systems. IDF parameters indicate that the maximum rainfall intensity of 66.55 mm/hr and 73.92 mm/hr can be expected for a storm of one hour for 25 and 50 years return period, respectively.

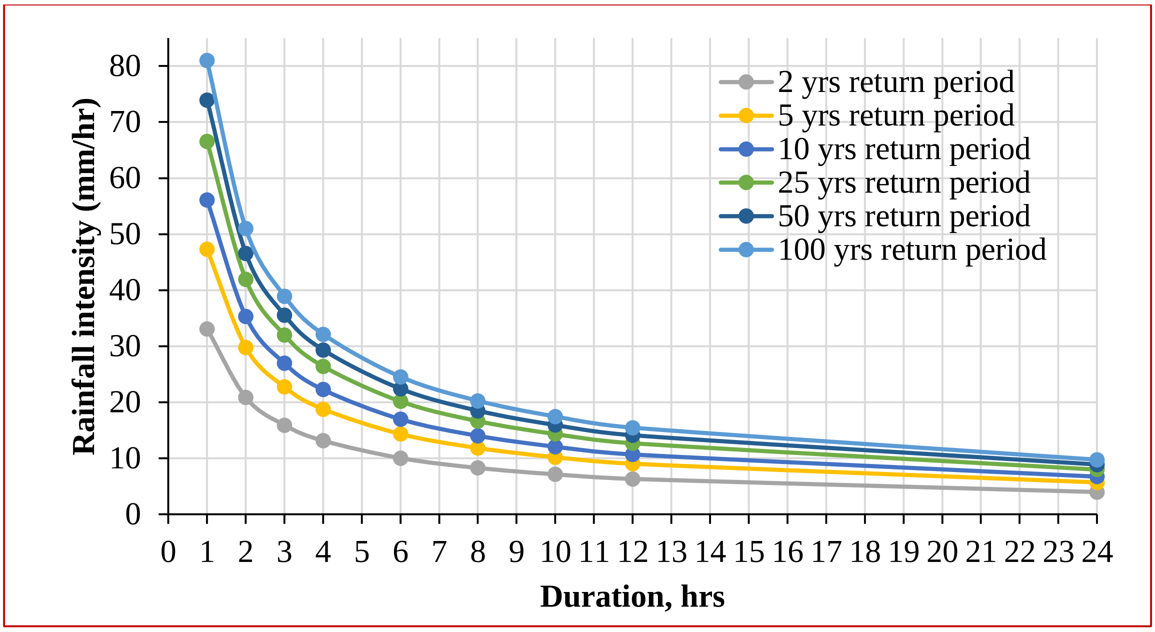


Fig. 5.13. IDF curves of precipitation (1901-2018)

5.6 Flow Duration Curves

Flow Duration Curves (FDC) shows relationship between any given discharge and % of time that discharge is exceeded (Fig.5.14). It can be used for estimation of dependable flows for water availability and distribution planning in the study area.

5.7 Springs sustainability analysis

The springs sustainability analysis was carried out using scientific approach (Netopil, 1971) as per four different categories namely Extraordinary balanced, Well-balanced balanced, unbalanced and Extraordinary unbalanced. The reliability index are found to be 3.7 for the hill campus spring and 15.31 for the Fakua spring (Table 5.5). This results indicated that Ranichauri hill campus spring is well balanced, while Fakua spring is extraordinarily unbalanced. Hill campua spring found less variable (58.91%) as compared to Fakua spring (143.54%). This reveals that needs urgent rejuvenation/catchment treatment measures for the Fakua spring. The detailed analysis is presented in Table 5.6. Also, presented variation in precipitation and spring discharge at hill campus spring, Ranichauri (Fig.5.15). The study indicated that spring flow characterization is necessary to understand the natural water resource potential of the springshed.

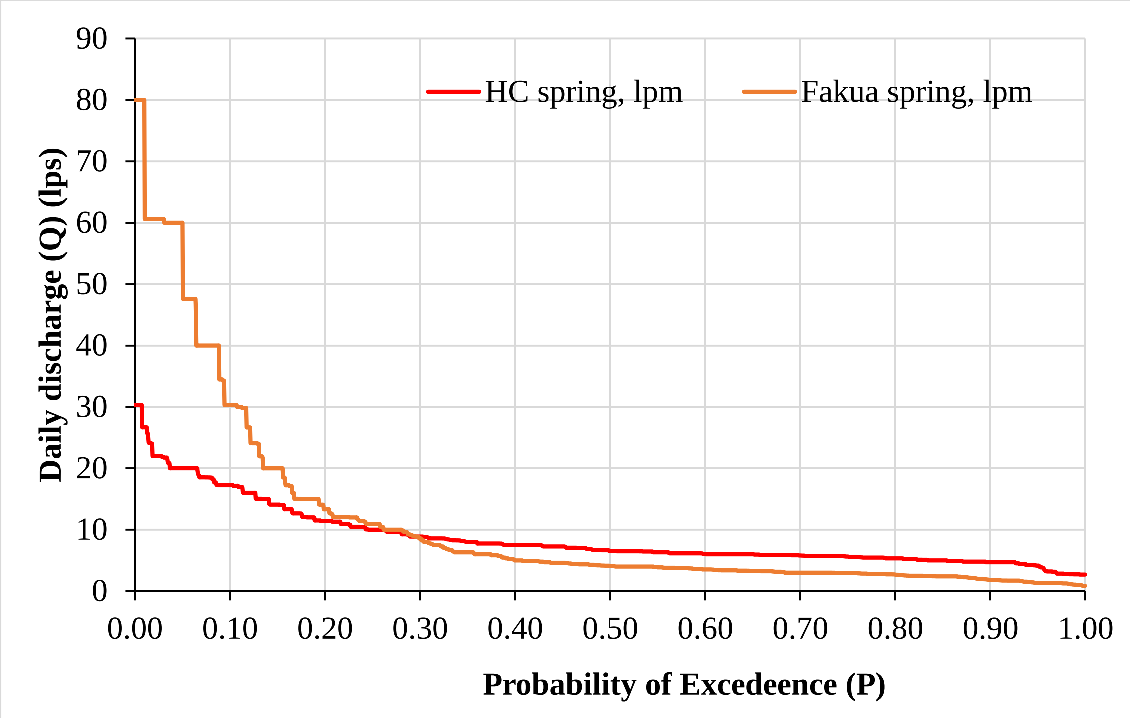


Fig. 5.14. Flow duration curves of selected springs.

Table 5.5. Performance of the selected Springs

SN	Parameter/Spring	HC Spring	Fakua Spring
1	Minimum flow (Qmin) (lpm)	2.69	0.86
2	Maximum flow (Qmax) (lpm)	30.3	80
3	Average flow (Qavg) (lpm)	8.71	10.85
4	Variability (%)	**58.91**	**143.54**
5	Q10 (lpm)	17.4	30
6	Q90 (lpm)	4.7	1.96
7	**Reliability Index (Q10%/Q90%)**	**3.7**	**15.31**
8	**Remark**	**Well-balanced**	**Extraordinarily unbalanced**

Table 5.6. Classification of springs (Netopil, 1971)

SN	Q10%/Q90%	Spring Type
1	1.0-2.5	Extraordinary balanced
2	2.6-5.0	Well balanced
3	5.1-7.5	Balanced
4	7.6-10.0	Unbalanced
5	>10	Extraordinary unbalanced

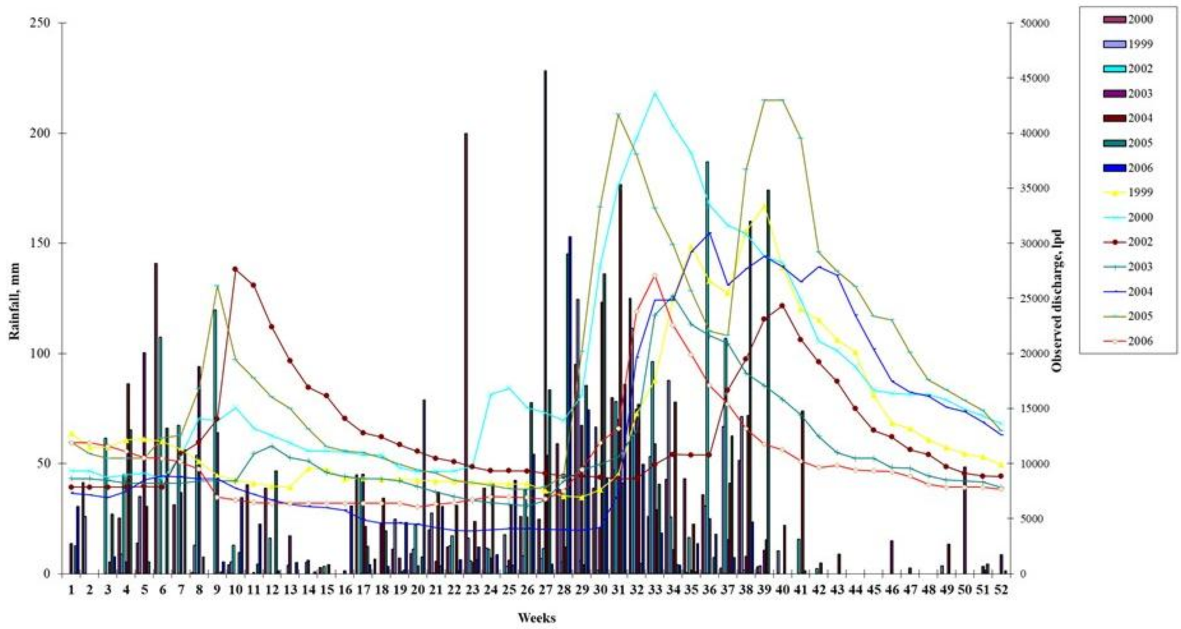


Fig. 5.15. Weekly variation in precipitation and spring discharge at hill campus spring, Ranichauri.

The study recommended that there is a need for more efforts on spring inventory preparation and identification of the present status and recharge areas of the springs in the Tehri Garhwal District.

6. SUMMARY AND CONCLUSIONS

9.1 Summary

The present study inventorized and characterized springs in Tehri-Garhwal district using GIS mapping, hydro-chemical, and isotopic analyses. Out of 401 springs identified, 50 were studied in detail, with Ranichauri and Fakua springs selected for sustainability assessment. Results showed alkaline water quality, significant hydro-climatic variability, and anthropogenic impacts on spring flow. While, Ranichauri spring remains balanced, Fakua spring requires urgent rejuvenation. The study emphasizes scientific interventions, water harvesting, and continuous monitoring to ensure sustainable spring management in the region.

9.2 Conclusions

- Conservation and management of springs require a clear understanding of watershed/springshed processes and climatic characteristics.
- A GIS-based inventory identified 401 springs in Tehri-Garhwal district, with detailed characterization of 50 springs.
- Hydro-chemical analysis revealed alkaline water (pH 6.8–8.5) with EC ranging from 40–1440 µs/cm.
- Isotopic analysis established a Local Meteoric Water Line (LMWL) and temporal isotopic variation of spring water.
- Precipitation trend analysis showed significant shifts, likely due to climate variability and anthropogenic activities.
- Developed IDF curves for precipitation and FD curves for spring flow provide tools for climate-smart water resource planning.
- Two representative springs (Ranichauri and Fakua) were studied in detail for sustainability assessment.
- Ranichauri spring was found to be well-balanced, while Fakua spring was highly unbalanced, requiring urgent rejuvenation measures.

9.3 Recommendations

Based on the various findings of the study, following recommendations are made:

- Scientific rejuvenation of springs through biological and engineering measures.
- Construction of water harvesting structures for dry-season supply.
- Regular monitoring of spring discharge and quality.
- Scaling out interventions based on hydrological investigations.

7. WAY FORWARD

The way forward emphasizes scientific interventions, participatory management, and climate-smart planning to ensure the long-term sustainability of springs in Tehri-Garhwal. By combining hydrological investigations with community-driven approaches, the district can secure its water resources against the dual challenges of anthropogenic pressures and climate change. The following detailed hydrological interventions with respect to springs rejuvenation by successful implementation of springshed/watershed management activities can be taken in the study region:

- **Expand Spring Inventory:** Continue comprehensive GIS-based mapping and field surveys to cover all springs in Tehri-Garhwal district, ensuring updated and accessible geo-databases.
- **Scientific Rejuvenation Measures:** Implement biological (afforestation, vegetative cover) and engineering interventions (percolation tanks, recharge trenches, check dams) in springsheds/watersheds to enhance recharge and .to supplement spring water availability during lean seasons.
- **Community Participation:** Involve local communities in spring protection, monitoring, and management, integrating traditional knowledge with scientific practices.
- **Climate-Smart Planning:** Use developed IDF and FD curves for designing resilient water resource systems that can withstand climate variability.
- **Regular Monitoring & Data Sharing:** Establish long-term monitoring of discharge, water quality, and isotopic composition, with open data platforms for researchers and policymakers.
- **Policy Integration:** Advocate for spring management to be included in district-level water resource planning and climate adaptation strategies.
- **Scaling Out Interventions:** Replicate successful rejuvenation models from the springs rejuvenation in the study region and apply them to other vulnerable springs like Fakua, ensuring sustainability across the region.

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ANNEXTURES

Annexure – I

Details of spring's

Selected springs further detailed investigations.

Annexure – II

Short term Training organized

A two-days training programme on “Springshed Management & Rejuvenation through Scientific Data Collection and Processing Techniques” was organized for officers of Divisional Forest Office, Uttarakhand Forest Department Narendranagar, Uttarakhand at Rishikesh during August 24-25, 2021. Around 25 officers of different ranks & staffs of the forest department participated in the training.

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- Pingale SM, SS Rawat, Sudhir Kumar, SD Khobragade (2022) Assessment of sustainability of springs using field survey, isotopic characterisation and statistical techniques in Tehri-Garhwal district, Uttarakhand (under process).

SOFTWARE/DATA USED IN THE STUDY

1. MATLAB
2. ArcGIS
3. Xlstat

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