Template/Pro forma for Submission

NMHS-Himalayan Institutional Project Grant

NMHS-FINAL TECHNICAL REPORT (FTR)

Demand-Driven Action Research and Demonstrations

NMHS Grant Ref. No.:	NMHS/2020-21/MG77/77

Date of Submission:	0	3	0	8	2	0	2	3
	d	d	m	m	y	y	y	y

PROTOCOL FOR REJUVENATION OF SPRINGS IN UTTARAKHAND WITH DUE PREPAREDNESS FOR CLIMATE CHANGE

Project Duration: *from* (**15.07.2020**) *to* (**15.01.2023**).

***Submitted to*:**
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Contents

NMHS-Final Technical Report (FTR)

Demand-Driven Action Research Project

DSL: Date of Sanction Letter

2	5	0	6	**2**	**0**	**2**	**0**
d	d	m	m	y	y	y	y

DPC: Date of Project Completion

1	5	0	1	**2**	**0**	**2**	**3**
d	d	m	m	y	y	y	y

Part A: Project Summary Report

1. Project Description

i.	Project Grant Ref. No.:	NMHS/2020-21/MG77/77					
ii.	Project Category:	Small Grant		Medium Grant	✓	Large Grant	
iii.	Project Title:	**Protocol for Rejuvenation of Springs in Uttarakhand with due preparedness for climate change**					
iv.	Project Sites (IHR States/ UTs covered) (*Location Maps attached*):	Uttarakhand					
v.	Scale of Project Operation:	Local		Regional	✓	Pan-Himalayan	
vi.	Total Budget:	1.48,07,184 (in Cr)					
vii.	Lead Agency:	Amity Institute of Global Warming and Ecological Studies, AUUP					
	Lead PI/ Proponent:	Prof. Madhusoodanan M.S.					
	Co-PI/ Proponent:	Dr. Vartika Singh Dr. Maya Kumari					
viii.	Implementing Partners:	GB Pant National Institute for Himalayan Environment and Sustainable Development					
	Key Persons (Contact Details, Ph. No., E-mail):	Er. Soukhin Tarafdar Email: tarafdar101s@gmail.com					

2. Project Outcomes

2.1. Abstract/ Summary

Background: Most of the water consumed in the Himalayan region comes from springs. However, the increasing uncertainty of the spring water supply in the Himalayas has created a great problem for the people. Such impacts are observed mainly due to the impact of climate change on the precipitation patterns, anthropogenic causes and the topography, vegetation cover, soil and geology of an area. These factors control the rainfall runoff and groundwater recharge and storage. In order to ensure water security in such villages, spring shed management approach is undertaken. Amity Institute of Global Warming and Ecological Studies (AIGWES) is an international institute that aims at enhancing the understanding of global warming, its causes, possible mitigation options and the technical and social adaptation that would be required to deal with the consequences of warming that is unavoidable. As a part of this, AIGWES have collaborated with Peoples' Science Institute, (PSI), Dehradun to undertake Ground Survey, Social PRA Survey, Hydrogeological Survey Information of springs Land Use & Geological Mapping, Community Mobilization & Capacity Building, Water Quality Analysis & Monitoring, Treatment & Restoration measures of Springs in Pauri and Tehri Garhwal districts of Uttarakhand.

Objectives/ Aim:

The main objectives of this project are as follows:

1. To study 6 identified spring sheds - 3 each in Tehri and Pauri Garhwal districts of Uttarakhand
2. To geo-tag 120 or more springs (20 springs in each) on the basis of maximum dependency or minimum discharge.
3. To select 30 springs (5 springs in each) and identify their micro-spring sheds through stratified random sampling.
4. To conduct a detailed study for the selected 30 springs.
5. Protocol for rejuvenation of springs.

Methodology:

The inventory and spring data were prepared and analyzed after proper survey carried out on field.

Approach:

1. Social PRA Survey: After delineation of the springshed area, social PRA is the next very important step to understand the social dynamics. It includes (a) Collection of Social Census data, (b) Information of springs in the probable recharge area like developmental activities, agriculture, forest type etc. (c) Collection of household dependency data (d) Collection of water usage data, for example: drinking, domestic, irrigation etc. (e) Collection of data for existing or proposed road networks in the area. (f) Collection of data for previously tapped springs. (g) Knowledge about past soil and water conservation measures.

2. Hydrogeological Survey: For the better understanding of the springs and delineation of recharge area, hydrogeological data is quite important. It includes collection of basic hydrogeology data for 120 springs and detailed hydrogeological study for 30 critical springs. The parameters considered for the study include (a) Latitude and Longitude (b) Discharge Rate (c) Geology - Rock and Aquifer type (d) Ground Configuration- Aspect, Slope, drainage (e) Spring Typology & Seasonality (f) Chal-Khal and Handpump information (g) Landslide occurrence (h) Identifying & Mapping of fractures (i) Soil Mapping

3. Water Quality Analysis: During the Social PRA and Hydrogeological Surveys, water quality analyses were be carried out. These analyses were performed in two stages: (a) *In situ* water testing: This test will

be performed for all the 120 springs and is carried out on field. The parameters like pH, TDS, EC and discharge are included in this test (b) Laboratory testing: water samples from 30 critical springs will be collected and brought to the laboratory for detailed testing of selected parameters.

4. Restoration Measures: Once the 30 critical springs and their recharge areas are delineated, restoration measures will be implemented in those areas. It includes: (a) Revival measures for Chal- Khal (b) Scope of failed hand pumps for ground water recharge (c) Remedy of Landslide (d) Revival plan for enhancing percolation in abandoned agricultural lands (e) Treatment measures & its operation and maintenance

5. Primary Data Collection: After the treatment measures were implemented, the selected critical springs were monitored for a one year of understand the impacts of the treatment measures. The data sets collected over the current one year include:

   a) Discharge data
   b) Rainfall data

6. Biodiversity mapping: As we know that biodiversity is one of the major and important parameters for spring rejuvenation, detailed study of plants has been conducted in 04 spring sheds (06 identified critical springs in each spring shed). The data was collected from past 06 months included.
   a) Basic information of springs
   b) Humidity and Temperature
   c) Geo co-ordinates
   d) Legal status of the recharge area and land use
   e) Rock and geology, and different basic soil parameters
   f) Crop composition
   g) Regeneration status
   h) Injury/damage to crop, and disturbance intensity
   i) presence of grasses and weeds
   j) j) plantation status
   k) Identify the degradation drivers
   l) Ffaunal sighting (flagship species)
   m) Faunal traces of flagship species
   n) Vegetation analysis (by using different methods, trees, shrubs, herbs, grasses and climbers have been mapped)
   o) Identification of indicator species.

***Results*:**

1. Biodiversity mapping: Biodiversity of 04 springsheds (one in Tehri and three in Pauri districts) has been mapped with the help of different methods.
2. Hydrogeological maps prepared for 6 selected water sheds.
3. Climate projection analyses have been done for the State of Uttarakhand for the near-future.
4. Engineering structures were made for recharging the selected springs.
5. Indicator plant species were identified for the selected springsheds.
6. Water porosity analysis.
7. Water Quality and flow rate measurements.

Conclusions:

Managing water in 21st century in complex sloping landscape of middle Himalaya will need more holistic understanding of soil, hydrogeology, landuse, forest, hydrometeorology and the recent changes including climate change. More so, the interaction between soil–water and landscape–soil-hydrology relationships should be studied in greater details. The present study highlights that the near-surface, topsoil and the sub-soil are showing very low hydraulic conductivity which indicate a high runoff potential of the soil formation in permanent fallow land which dominates the landscape. The rainfall intensity measurements in close proximity from the adjoining watersheds show rainfall intensity of less than 2.5 mm/hour (light intensity) dominates the monsoon rainfall event and likely to cause overland flow in most of the rainfall event under saturated condition of soil. Agricultural land abandonment with livestock trampling have caused the compaction of soil in recent times and hence necessitate appropriate land management.

Recommendations/ Way Forward with Exit Strategy:

Documentation of the successful interventions, lessons learned, and best practices from the project is important. This information should be disseminated widely through reports, case studies, workshops, and conferences. Sharing knowledge and experiences will facilitate replication of successful approaches in other areas. Foster collaboration and partnerships with relevant stakeholders, including government agencies, non-governmental organizations, research institutions, and local communities. Collaborative efforts can enhance the project's impact, leverage expertise, and share resources and knowledge for a more comprehensive approach to spring rejuvenation. Advocate for the integration of spring rejuvenation principles and approaches into relevant policies, regulations, and development plans at the regional and national levels. Engage with policymakers and advocate for supportive frameworks that promote sustainable water management and natural resource conservation.

2.2. Objective-wise Major Achievements

S. No.	Objectives	Major achievements (in bullets points)
1	To characterize hydrologic conditions of the springs during different seasons.	• Discharge monitoring and measurement for 30 critical springs was done in 6 watersheds.
2	To evaluate spring flow response from differing aquifer geometries and geophysical methods.	• Detailed geological mapping and cross section were prepared for each watershed.
3	To revive dying springs in Himalayas: groundwater recharge using geo-hydrology technology	• Recharge areas identified. • Prepared porosity maps based on data. • Engineering measures carried out in the recharge area of spring in collaboration with the community. • Policy guidelines for parameters related to spring rejuvenation and biodiversity were prepared.
4	To develop a spring shed management protocol for maintenance and protection of springs with the help of local communities and other stakeholders	• Spring shed management protocol has been prepared.
5	To develop a database for springs, which includes classified maps, geological maps and record of spring discharge in different seasons	• Geological maps prepared for 6 watersheds.

6	Identification of indicator plant species for locating spring shed and prescription of engineering and vegetative measures best suited for water harvesting.	• Indicator plant species were identified for 6 watersheds and database prepared
7	Identify and restore the Time Tested Chal/khal and develop the training needs of Village/Community for their sustained maintenance.	• Spring flow database for Pauri Garhwal's springs (Bareth, Malan, Ghurdauri watersheds), and Tehri Garhwal's springs (Moldhar, Kotigad and Kaddukhal watersheds) have prepared.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, & Reason thereof:
1	Hydro-geological maps (with all essential parameters) of selected spring sheds in the selected districts for exploring ground water recharge techniques	Number of hydro-geological maps (with all essential parameters) of selected spring sheds (Nos.)	Hydro- geological maps for 6 watersheds has been prepared	
2	Policy prescription for managing forest in catchment with twin purpose of: a) Spring Rejuvenation and b) Biodiversity conservation	• Policy guidelines for parameters related to spring rejuvenation (Nos.) • Policy guidelines for biodiversity conservation associated with spring shed management (Nos.)	Protocol for spring rejuvenation	
3	Collection of weekly data for spring flow	Database for spring flow (Nos.)	Database created	
4	GIS database (detailed information about all essential parameters of selected watersheds) for policy makers	GIS database (detailed information about all essential parameters of selected watersheds) for policy makers (Nos.)	GIS database created	
5	Climate projections for the near-future (30 years)	Climate projections for near-future (30 years)	Analyses of climate projections were completed.	

6	Spring shed management protocol	• Spring shed management protocol (Nos) • Database of indicator plant species which are suitable for spring shed management(Nos.)	Based on the field observations and measurements, prepared springshed management protocol	
7	Database of indicator plant species which are suitable for spring shed management	• Number of Chal/khals identified and restored (Nos.) • Number of beneficiaries village/ local people (Nos.)	Database prepared for indicator plant species which are suitable for spring shed management	

2.4. Strategic Steps with respect to Outcomes

S. No.	Particulars	Number/ Brief Details	Remarks/ Attachment
1.	New Methodology developed		
2.	New Models/ Process/ Strategy developed		
3.	New Species identified		
4.	New Database established	Database on spring flow, GIS and indicator plant species for 6 springsheds were developed	
5.	New Patent, if any	Nil	
	I. Filed (Indian/ International)		
	II. Granted (Indian/ International)		
	III. Technology Transfer(if any)		
6.	Others (if any)		

3. New Data Generated over the Baseline Data

S. No.	New Data Details	Status of Existing Baseline	Additionality and Utilisation New data
1	GIS database for 6 spring sheds		The new data generated can be utilised for other research and field implementation projects on land use management, land-scaping, water resources management etc.
2	Spring flow measurements		The data provide a basis for future observations.
3	Indicator plant species database		The dataset developed may be utilised for implementing land restoration works and biodiversity conservation.

4. Demonstrative Skill Development and Capacity Building/ Manpower Trained

S. No.	Type of Activities	Details with number	Activity Intended for	Participants/Trained			
				SC	**ST**	**Woman**	**Total**
1.	Workshops	2 workshops	Community based spring shed Management			**43**	**66**
2.	On Field Trainings	6 trainings	Para workers training on monthly water quality, discharge and Rainfall monitoring	**1**	**1**	**3**	**6**
3.	Skill Development	24 trainings in 6 watersheds (4 trainings in each watershed)	Para workers training on seasonal water quality testing (Winter and summer for two years)	**1**	**1**	**3**	**6**
4.	Academic Supports						
	Others (if any)						

5. Linkages with Regional & National Priorities (SDGs, INDC, etc.)/ Collaborations

S. No.	Linkages /collaborations	Detail of activities (No. of Events Held)*	Beneficiaries
1.	Sustainable Development Goal (SDG)	SDG -3, 5, 6, 8, 10, 11, 12, 13	Villagers surrounding the selected 6 springsheds
2.	Climate Change/INDC targets	Reducing energy consumption	
3.	International Commitments	Paris Agreement	
4.	Bilateral engagements		
5.	National Policies	Creating additional carbon sink through forest and tree cover Promoting sustainable lifestyles and patterns of consumption	
6.	Others collaborations	• Uttarakhand Jal Sansthan • People's Science Institute	

Note: Further details may be summarized in DPR Part-B, Section-6. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

6. Project Stakeholders/ Beneficiaries and Impacts

S. No.	Stakeholders	Support Activities	Impacts
1.	Gram Panchayats		
2.	Govt Departments (Agriculture/ Forest)		
3.	Villagers	Mobilization of villagers for their natural resources	Now they are aware of the importance of protecting their springs and forest and involved in this
4.	SC Community	Everyone was encouraged to work equally	
5.	ST Community	Everyone was encouraged to work equally	
6.	Women Group	Strengthen and mobilaization of water user groups	
	Others (if any)		

Note: Further details may be summarized in DPR Part-B, Section-6. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

7. Financial Summary (Cumulative)

Please attach the consolidated and audited Utilization Certificate (UC) and Year-wise Statement of Expenditure (SE) separately, *ref*. **Annexure I.**

The document is attached as Annexure I

8. Major Equipment/ Peripherals Procured under the Project

S#	Name of Equipment	Quantity	Cost (INR)	Utilisation of the Equipment after project
1	Garmin Receiver e Trex30X (GPS)	10	1,84,800.00	Used by AIGWES
2	Digital Hand Held Hygro-Thermometer	6	64,008.00	Used by AIGWES
3	HP Desktop 280 Pro GS MT PC (7TE09AV)	01	64,995.00	Used by AIGWES
4	Laptop HP13-BB0078TU	01	80,850.00	Used by AIGWES

9. Quantification of Overall Project Progress

S. No.	Parameters	Total (Numeric)	Remarks/ Attachments/ Soft copies of documents
1.	IHR States/ UTs covered:	*1*	
2.	Project Sites/ Field Stations Developed:	*6*	
3.	Scientific Manpower Developed (PhD/M.Sc./JRF/SRF/ RA):		*2 JRF and 6 Project Assistants were trained.* *a) Guru Sai Krishna Vidhata (JRF)* *b) Shashi Upadhyay (Project Assistant)* *c) Kamal Singh Rawat (Project Assistant)* *d) Vivek Yadav (Project Assistant)* *e) Roshan Lal (Project Assistant)* *f) Akansha Mehra (Project Assistant)* *g) Arti Srivastava (Project Assistant)* *JRF appointed by Partner Institute*
4.	Livelihood Options promoted		
5.	Technical/ Training Manuals prepared		
6.	Processing Units established, if any		
7.	No. of Species Collected, if any		
8.	No. of New Species identified, if any		
9.	New Database generated (Types):		
	Others (if any)		

Note: Further details may be summarized in DPR Part-B. Supporting materials may be enclosed as annexure/ appendix separately to the FTR.

10. Knowledge Products and Publications:

S#	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures
		National	International		
1.	Journal – Research Articles/ Special Issue:				
2.	Book – Chapter(s)/ Monograph/ Contributed:				
3.	Technical Reports:	1			In progress
4.	Training Manual (Skill Development/ Capacity Building):	1			In progress
5.	Papers presented in Conferences/Seminars:				
6.	Policy Drafts/Papers:	1			In progress
7.	Others, if any:				

11. Recommendation on Utility of Project Findings, Replicability and Exit Strategy

Particulars	Recommendations
Utility of the Project Findings:	The findings of the project can be used to inform policy decisions related to management of natural resources and water conservation in the Garhwal region. Policymakers can use the findings to identify effective strategies for sustainable land use practices, water management, and conservation efforts.
Replicability of Project/ Way Forward:	The findings of the project can contribute to global knowledge on water conservation, natural resources management and sustainable development particularly in areas facing similar environmental challenges.
Exit Strategy:	Documentation of the successful interventions, lessons learned, and best practices from the project is important. This information should be disseminated widely through reports, case studies, workshops, and conferences. Sharing knowledge and experiences will facilitate replication of successful approaches in other areas. Foster collaboration and partnerships with relevant stakeholders, including government agencies, non-governmental organizations, research institutions, and local communities. Collaborative efforts can enhance the project's impact, leverage expertise, and share resources and knowledge for a more comprehensive approach to spring rejuvenation. Advocate for the integration of spring rejuvenation principles and approaches into relevant policies, regulations, and development plans at the regional and national levels. Engage with policymakers and advocate for supportive frameworks that promote sustainable water management and natural resource conservation.

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(PROJECT PROPONENT/ COORDINATOR)

(Signed and Stamped)

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

Prof. (Dr.) Raj Kamal Kapur
Officiating Registrar
AMITY UNIVERSITY
UTTAR PRADESH

Place: Noida
Date: 01/08/2023

PART B: DETAILED PROJECT REPORT

The Detailed report should include an Executive Summary and it should have separate chapters on (i) **Introduction**, (ii) **Methodologies/Strategy/Approach**, (iii) **Key Findings and Results**, (iv) **Overall Achievements**, (v) **Project's Impacts in IHR** (vi) **Exit Strategy** and Sustainability, (vii) **References**, and (viii) **Acknowledgements** (acknowledging the financial grant from the NMHS, MoEF&CC, GoI).

Other necessary details/ Supporting Documents/ Dissemination Materials (*New Products/ Manuals/ Standard Operating Procedures (SOPs)/ Technology developed/Transferred, etc, if any*) may be attached as Appendix(ces).

1 EXECUTIVE SUMMARY

Most of the water consumed in the Himalayan region comes from springs. However, the increasing uncertainty of the spring water supply in the Himalayas has created a great problem for the people. Such impacts are observed mainly due to the impact of climate change on the precipitation patterns, anthropogenic causes and the topography, vegetation cover, soil and geology of an area. These factors control the rainfall runoff and groundwater recharge and storage. In order to ensure water security in such villages, spring shed management approach is undertaken. Amity Institute of Global Warming and Ecological Studies (AIGWES) is an international institute that aims at enhancing the understanding of global warming, its causes, possible mitigation options and the technical and social adaptation that would be required to deal with the consequences of warming that is unavoidable. As a part of this, AIGWES have collaborated with Peoples' Science Institute, (PSI), Dehradun to undertake Ground Survey, Social PRA Survey, Hydrogeological Survey Information of springs Land Use & Geological Mapping, Community Mobilization & Capacity Building, Water Quality Analysis & Monitoring, Treatment & Restoration measures of Springs in Pauri and Tehri Garhwal districts of Uttarakhand.

Objectives/ Aim:

The main objectives of this project are as follows:

1. To study 6 identified spring sheds - 3 each in Tehri and Pauri Garhwal districts of Uttarakhand
2. To geo-tag 120 or more springs (20 springs in each) on the basis of maximum dependency or minimum discharge.
3. To select 30 springs (5 springs in each) and identify their micro-spring sheds through stratified random sampling.
4. To conduct a detailed study for the selected 30 springs.

Methodology:

The inventory and spring data were prepared and duly completed after proper survey carried out on field.

Approach:

1. **Social PRA Survey**: After delineation of the springshed area, social PRA is the next very important step to understand the social dynamics. It includes (a) Collection of Social Census data, (b) Information of springs in the probable recharge area like developmental activities, agriculture, forest type etc. (c) Collection of household dependency data (d) Collection of water usage data, for example: drinking, domestic, irrigation etc. e) Collection of data for existing or proposed road networks in the area. (f) Collection of data for previously tapped springs. g) Knowledge about past soil and water conservation measures.

2. **Hydrogeological Survey**: For the better understanding of the springs and delineation of recharge area, hydrogeological data is quite important. It includes collection of basic hydrogeology data for 120 springs and detailed hydrogeological study for 30 critical springs. The parameters considered for the study include (a) Latitude and Longitude (b) Discharge Rate (c) Geology - Rock and Aquifer type (d) Ground Configuration- Aspect, Slope, drainage (e) Spring Typology & Seasonality (f) Chal-Khal and Handpump information (g) Landslide occurrence (h) Identifying & Mapping of fractures (i) Soil Mapping

3**. Water Quality Analysis**: During the Social PRA and Hydrogeological Surveys, water quality analysis will be carried out. This analysis will be performed in two stages: a) In-situ water testing: This test will be performed for all the 120 springs and is carried out on field. The parameters like pH, TDS, EC and discharge are included in this test b) Laboratory testing: water samples from 30 critical springs will be collected and brought to the laboratory for detailed testing of selected parameters.

4. **Restoration Measures**: Once the 30 critical springs and their recharge areas are delineated, restoration measures will be implemented in those areas. It includes: (a) Revival measures for Chal- Khal (b) Scope of failed hand pumps for ground water recharge (c) Remedy of Landslide (d) Revival plan for enhancing percolation in abandoned agricultural lands (e) Treatment measures & its operation and maintenance

5. **Primary Data Collection**: once treatment measures are implemented, the selected critical springs are monitored for a one year of understand the impacts of the treatment measures. The data sets collected over the current one year include:

a) Discharge data

b) Rainfall data

6. Biodiversity mapping: As we know that biodiversity is one of the major and important parameters for spring rejuvenation, detailed study of plants has been conducted in 04 springsheds (06 identified critical springs in each springshed). The data was collected from past 06 months included.

a. Basic information of springs
b. Humidity and Temperature
c. geo co-ordinates
d. Legal status of the recharge area and land use
e. Rock and geology, and different basic soil parameters
f. Crop composition
g. Regeneration status
h. Injury/damage to crop, and disturbance intensity
i. presence of grasses and weeds j) plantation status
j. Identify the degradation drivers
k. faunal sighting (flagship species)
l. faunal traces of flagship species
m. Vegetation analysis (by using different methods, trees, shrubs, herbs, grasses and climbers have been mapped)
n. Identification of indicator species.

***Results*:**

- Biodiversity mapping: Biodiversity of 04 springsheds (one in Tehri and three in Pauri districts) has been mapped with the help of different methods.
- Hydrogeological maps prepared for 6 selected water sheds.
- Climate projection analyses have been done for the State of Uttarakhand for the near-future.
- Engineering structures were made for recharging the selected springs.
- Indicator plant species were identified for the selected springsheds.

- Water porosity analysis
- Water Quality and flow rate measurements

2 INTRODUCTION

2.1 Background

Mountain springs are the primary source of water for rural households in the Himalayan region. For many people, springs are the sole source of water. A major proportion of drinking water supply in the mountainous parts of Uttarakhand is spring based. Despite their pivotal role, springs have not received their due attention. Many natural springs and water bodies are drying up. Spring discharge is reported to be declining due to mismanagement of recharge areas, land use change, and ecological degradation. With climate change and rising temperatures, rise in rainfall intensity and reduction in its temporal spread (Table-1), and a marked decline in winter rain, the problem of dying springs is being increasingly felt across Uttarakhand. A survey done by Uttarakhand Jal Sansthan (2016) reported that the water discharge has declined in more than half of the spring-source water schemes in the State. It is a dangerous sign that recharge aquifers are depleting in a State which is almost entirely dependent on springs for drinking water and other livelihood activities. The tradition recharge structures like old chal-khal and naulas are drying up due to lack of proper maintenance.

The hilly region of the State is badly gripped with migration. The migration is so huge that many villages have been left with population of single digit. Government of Uttarakhand has thus set up" Uttarakhand Rajya Gramin Evam Palayan Ayog". Himalayas are very vulnerable to climate change which is impacting the precipitation patterns. It is likely to aggravate the situation further. The concept of spring shed management is not very prominent in government agency planning, they give preference to high head pumping schemes of water from rivers flowing, but in recent years there has been an upsurge of studies and initiatives to address spring management in India, given the seriousness of the emerging crises around springs. These have been mostly community-centric initiatives that have looked at distribution rather than conservation and regeneration, although they have helped in mitigating the rural water crises to some extent. The concept of spring shed management – that is management of the area of recharge of springs, down to the area of discharge, is now getting increasingly well ingrained in the form of pilots of varying scales across Uttarakhand.

The concept of spring shed management entails that recharge areas be correctly identified through the use of simple field based study of hydrogeology, community knowledge and appropriate recharge measures are then undertaken to revive the springs. This study focussed on the management of the area of recharge of springs down to the area of discharge and development of protocol across Uttarakhand.

2.2 Overview of the major issues addressed

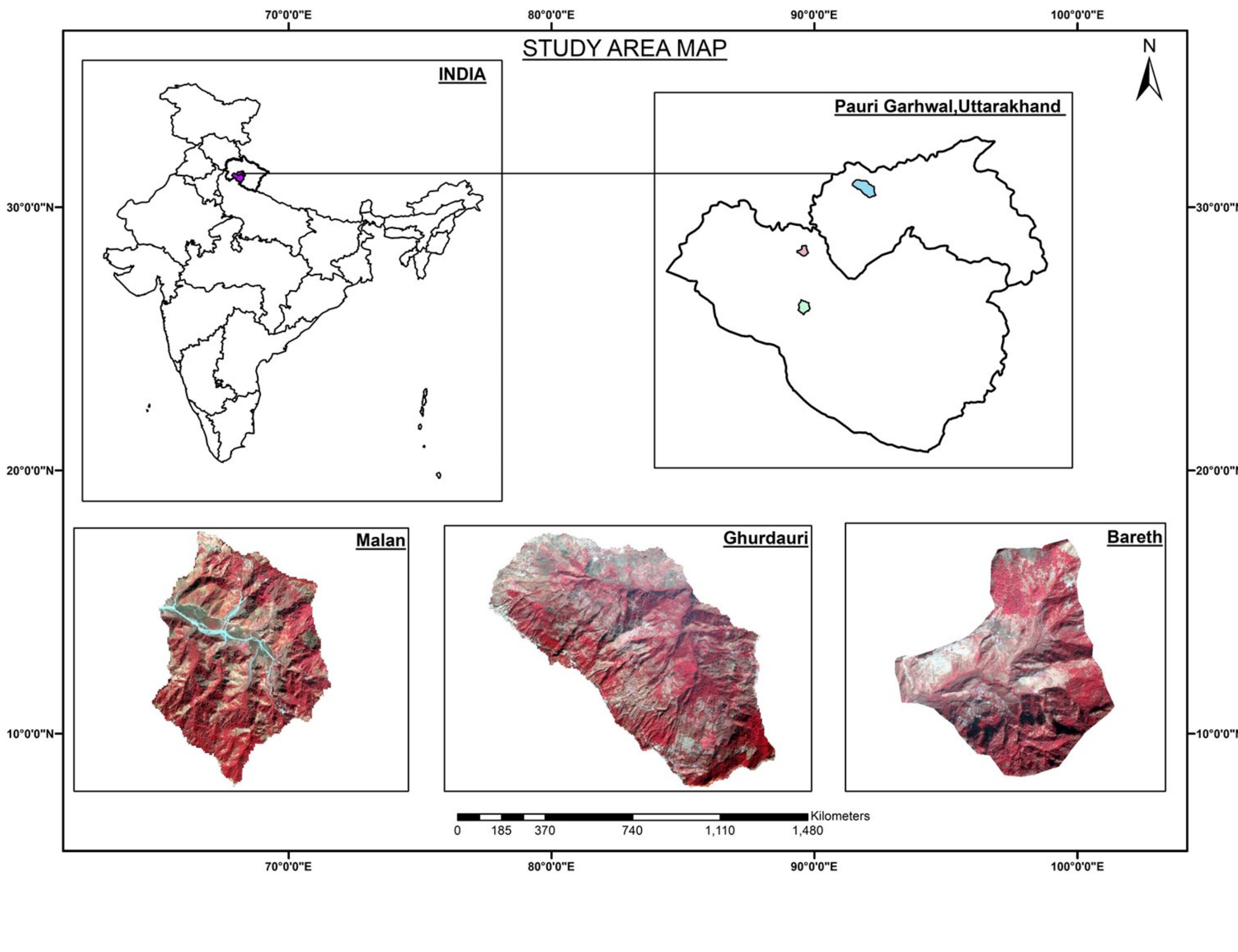
To characterize hydrologic conditions of the springs, a spring inventorization was carried out in the selected blocks of Pauri Garhwal and Tehri Garhwal districts. Out of this spring inventory, the identified springs in the were monitored for discharge estimation along with the rainfall measurements. Weekly monitoring was done to understand the hydrologic conditions of the critical springs. Further, the hydrologic data were analysed in understanding the discharge variation due to rainfall pattern changes and seasonal variations in the spring discharges.

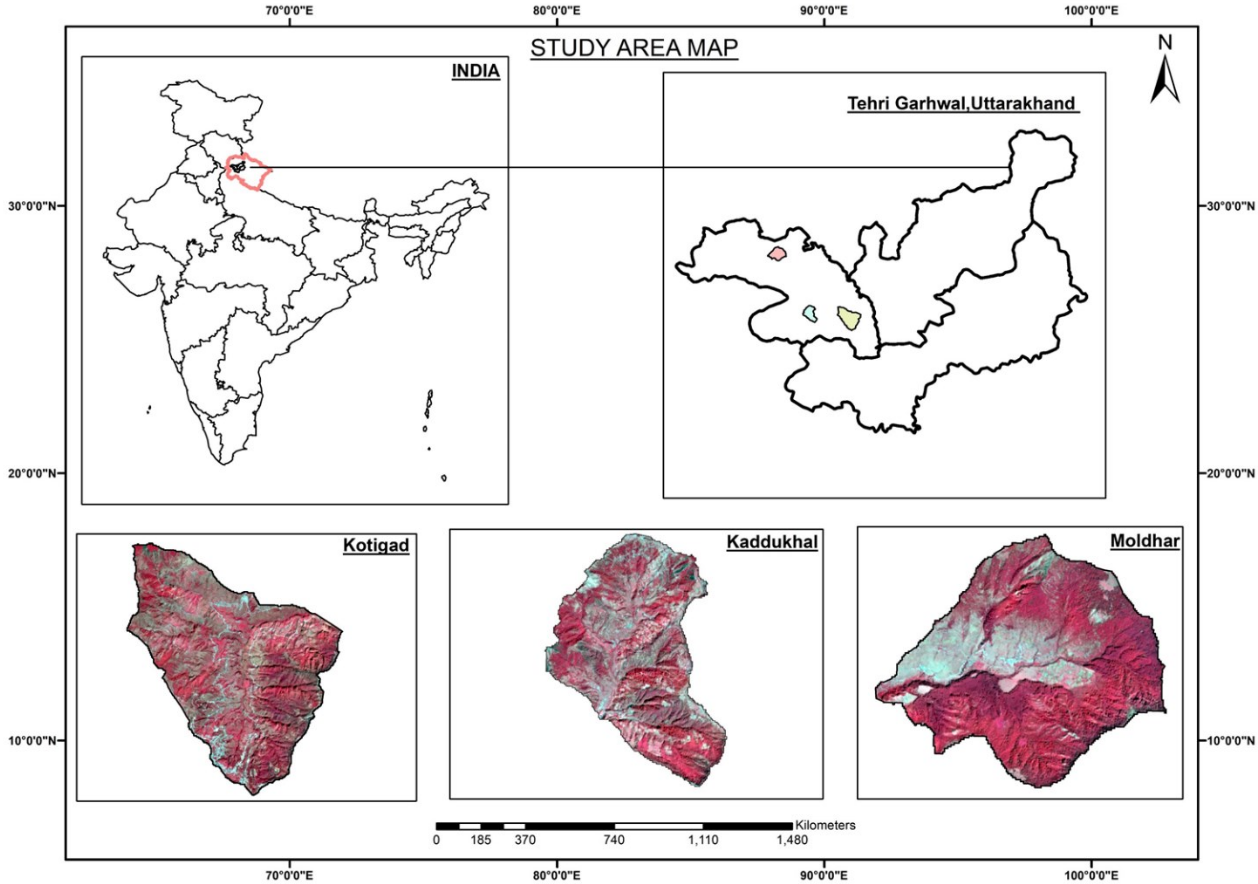
Evaluation of spring flow response from differing aquifer geometries and geophysical methods were carried out. The selection of springs was based on geological typology (depression springs, fracture springs, contact springs etc.). The groundwater recharge techniques were suggested based on the hydrogeological maps developed to specify the recharge areas of these selected springs. The maps are conceptual maps depending on the geology of these springs. Geophysical techniques were applied to find the geological strata of the spring systems.

Deforestation in mountain areas causes an increase in surface runoff and soil erosion which lead to decrease in fodder and water availability. This forces the inhabitants to reduce their livestock which, in turn, leads to loss of soil fertility and reduced agricultural production. The response is inevitable migration of the working persons which further aggravates the situation. Suitable plant species were identified in the selected spring sheds catchment area and plantation was done with the participation of local community.

2.3 Baseline Data and Project Scope

We have selected three watersheds each from Pauri Garhwal (Bareth Watershed, Malan Watershed, and Ghurdauri Watershed) and Tehri Garhwal (Moldhar Watershed, Kaddukhal Watershed, and Kotigad Watershed) for detailed watershed study. We have collected 12 years of rainfall data from the selected watershed sites in Pauri Garhwal and Tehri Garhwal, specifically from 2011 to 2022. This rainfall data will serve as a baseline for quantifying different hydrological processes operating in each basin. This database will serve as a foundation for further research and development activities.





Project Scope

The importance of spring water as a lifeline for the population in the Himalayas cannot be overstated. Approximately one-third of the Himalayan population relies entirely on spring water for their domestic needs and often for their livelihoods. However, these vital water sources are facing depletion, and there has been a lack of attention towards addressing this issue.

- Many factors contribute to the drying up of Himalayan springs, and their depletion has severe consequences for the communities dependent on them. Recognizing the significance of springs, efforts should be made to rejuvenate them, as it can provide a climate-resilient solution for livelihoods and ecosystems in hilly and mountainous regions. Moreover, rejuvenation efforts can enhance water access and contribute to achieving the Sustainable Development in Himalayan region.
- An aquifer-based approach, known as springshed management, holds great promise for the revival of springs. This approach, backed by various experiences, combines scientific knowledge, partnerships, and community participation to revive springs.
- Adopting the springshed management approach, stakeholders can work together to assess aquifer conditions, identify potential recharge areas, and implement appropriate measures to restore and sustainably manage springs. This approach not only addresses the immediate water needs of the communities but also promotes long-term sustainability and resilience.
- It is crucial to prioritize the revival of springs and allocate resources to research, policy development, and on-ground implementation to ensure the continued availability of this vital water source. The Himalayan region can safeguard its ecosystems, support livelihoods, and contribute to achieving broader sustainable development goals.

- Develop policy guidelines for parameters related to spring rejuvenation and biodiversity conservation associated with spring-shed management.

2.4 Project Objectives and Target Deliverables (as per the NMHS-Sanction Order)

Project Objectives	**Quantifiable Deliverables**
• To characterize hydrologic conditions of the springs during different seasons. • To evaluate spring flow response from differing aquifer geometries and geophysical methods. • To revive dying springs in Himalayas: groundwater recharge using geo-hydrology technology • To develop a spring shed management protocol for maintenance and protection of springs with the help of local communities and other stakeholders • To develop a database for springs, which includes classified maps, geological maps and record of spring discharge in different seasons • Identification of indicator plant species for locating springshed and prescription of engineering and vegetative measures best suited for water harvesting. • Identify and restore the Time Tested Chal/khal and develop the training needs of Village/Community for their sustained maintenance.	• Hydro-geological maps (with all essential parameters) of selected spring sheds in the selected districts for exploring ground water recharge techniques • Policy prescription for managing forest in catchment with twin purpose of a) Spring Rejuvenation and b) Biodiversity conservation • Collection of weekly data for spring flow • GIS database (detailed information about all essential parameters of selected watersheds) for policy makers • Climate projections for selected watersheds for the near-future (30 years) • Spring shed management protocol • Database of indicator plant species which are suitable for spring shed management

3 METHODOLOGIES/STARTEGY/ APPROACH

3.1 Methodologies used

The first step was the development of an inventory of available water resources. This includes identifying the water resources, storage facilities and distribution networks that are currently in place. It is crucial to analyse the condition of these resources and determine whether they are sufficient to meet the needs of the local communities and ecosystems. The next step was to check and identify, if any, the gaps or deficiencies in the current inventory. Spring data collection includes identifying the location of springs, assessing their flow rates and water quality and monitoring the temporal evolution of these factors. The inventory and spring data were finalized after conducting detailed field survey in the following approach.

1. Social Participatory Risk Assessment (PRA) Survey

After delineation of the spring shed area, social PRA is the succeeding very important step to understand the social dynamics. It includes (a) Collection of Social Census data, (b) Information of springs in the probable recharge area like developmental activities, agriculture, forest type etc. (c) Collection of household dependency data (d) Collection of water usage data, for example: drinking, domestic, irrigation etc. (e) Collection of data for existing or proposed road networks in the area. (f) Collection of data for previously tapped springs. (g) Knowledge about past soil and water conservation measures.

2. Hydrogeological Survey

For the better understanding of the springs and delineation of recharge area, hydrogeological data is quite important. It includes collection of basic hydrogeology data for 120 springs and detailed hydrogeological study for 30 critical springs. The parameters considered for the study include (a) Latitude and Longitude (b) Discharge Rate (c) Geology - Rock and Aquifer type (d) Ground Configuration- Aspect, Slope, drainage (e) Spring Typology & Seasonality (f) Chal-Khal and Handpump information (g) Landslide occurrence (h) Identifying & Mapping of fractures (i) Soil Mapping

3. Water Quality Analysis

During the Social PRA and Hydrogeological Surveys, water quality analyses were be carried out. These analyses were performed in two stages: (a) In situ water testing: This test will be performed for all the 120 springs and is carried out on field. The parameters like pH, TDS, EC and discharge are included in this test (b) Laboratory testing: water samples from 30 critical springs will be collected and brought to the laboratory for detailed testing of selected parameters.

4. Restoration Measures

Once the 30 critical springs and their recharge areas are delineated, restoration measures will be implemented in those areas. It includes: (a) Revival measures for Chal- Khal (b) Scope of failed hand pumps for ground water recharge (c) Remedy of Landslide (d) Revival plan for enhancing percolation in abandoned agricultural lands (e) Treatment measures & its operation and maintenance

5. Primary Data Collection

After the treatment measures were implemented, the selected critical springs were monitored for a one year of understand the impacts of the treatment measures. The data sets collected over the current one year include:

a) Discharge data
b) Rainfall data

6. Biodiversity mapping

As we know that biodiversity is one of the major and important parameters for spring rejuvenation, detailed study of plants has been conducted in 04 spring sheds (06 identified critical springs in each spring shed). The data was collected from past 06 months included.

a) Basic information of springs
b) Humidity and Temperature
c) Geo co-ordinates
d) Legal status of the recharge area and land use
e) Rock and geology, and different basic soil parameters
f) Crop composition
g) Regeneration status
h) Injury/damage to crop, and disturbance intensity
i) Presence of grasses and weeds
j) Plantation status
k) Identify the degradation drivers
l) Faunal sighting (flagship species)
m) Faunal traces of flagship species
n) Vegetation analysis (by using different methods, trees, shrubs, herbs, grasses and climbers have been mapped)
o) Identification of indicator species

7. Direct Injection of Rainwater to Aquifers

A novel technique has been developed using defunct or unused handpumps to recharge the aquifer directly connected to them with about 80-90% of the rain water received through rooftop or collected through surface runoff. This technique is very usefully for mountainous region.

Deep bore India Mark-II handpump has been successfully installed in Uttarakhand Mountain region since 1998. Due to various reasons, about 2000 in the hilly areas & 1517 in the plains, a total of 3517 hand pumps have been reported to be non-working/inoperative. The major reasons for becoming defunct is due to depletion/drying up of underground connected aquifers to the concerned handpumps.

These hand pumps have been working smoothly for the last 15-20 years, because the availability of water sources was good enough to pump water through these handpumps. These hand pumps were connected to underground aquifer and where the aquifer has depleted or dried up and not getting sufficient water for pumping through handpumps such handpumps has become defunct or non-operative. To revive these hand pumps, the aquifer/water sources located at a depth of 50-80m below have to be recharged, so that the hand pumps can become functional again. To revive defunct handpumps new technology has been developed. The details are provided in the Appendix.

3.2 Preparatory Actions and Agencies Involved

A Project Steering Committee was formed Under the Chairmanship of Shri. J.C. Kala to advise the Principal Investigator and Co Investigators to monitor the progress of the project work and assure that the project activities are on track. Two Technical Advisors were also included in the Project Steering Committee. Er. Soukhin Tarafdar, GBPNIHESD (partner institute) was also involved in this study. Uttarakhand Jal Sansthan and People Science Institute, Dehradoon were also collaborating with the project team in the field activities.

3.3 Data collected and Equipment utilized

It is a comprehensive study of Pauri Garhwal and Tehri Garhwal which conducted to assess the hydrogeological and social characteristics of six watersheds (Bareth, Malan, Ghurdauri, Kaddukhal, Kotigad, Moldhar) in Uttarakhand. The study included a detailed geological mapping, cross-sections, and identification of recharge areas for each watershed, which is critical information for understanding the groundwater system. The formation of water user groups for the critical springs is also an excellent approach to promote community participation and ownership in the management of water resources. It is encouraging to hear that engineering measures were designed and implemented in collaboration with the community to improve the recharge of the springs. The collection of data on Chal-Khal, soil infiltration, and soil mapping is also essential for understanding the groundwater recharge potential of the watersheds. The preparation of porosity maps will help identify areas that have higher recharge potential and areas where groundwater recharge is limited. It is great to see that water quality was monitored for two years in all seasons, as water quality is a critical factor that affects the sustainability of water resources. The appointment of Para workers to regularly collect discharge and rainfall data for critical springs will help track changes in groundwater levels and inform future management decisions.

The organization of community workshops to share experiences and challenges faced in the field is an excellent approach to promoting knowledge-sharing and learning among the community members. Overall, the study appears to have taken a holistic approach to managing watersheds, which is commendable.

Equipment Used:

- GPS units: Global Positioning System (GPS) units are commonly used in watershed surveys to collect accurate location data.
- Surveying equipment: Surveying equipment such as total stations and theodolites may have been used to measure angles, distances, and elevations for topographic mapping.
- Water Testing Kit: Water quality meters such as pH meters, conductivity meters, and dissolved oxygen meters may have been used to measure various parameters of water quality, such as acidity, salinity, and oxygen content.
- Hydrometer
- Cameras: Cameras are often used to capture visual information during field surveys, such as geologic features, land use, and water resources.
- Rock hammers and chisels

The following primary data were collected in Tehri Garhwal and Pauri Garhwal watersheds:

- Hydrogeological data, including detailed geological mapping, cross-sections, and identification of recharge areas for each watershed.
- Social survey data, including the formation of water user groups for the critical springs and community workshops to share experiences and challenges faced in the field.
- Engineering data, including the design and implementation of engineering measures (such as trenches and plantations) to improve the recharge of the springs.
- Data on Chal-Khal, soil infiltration, and soil mapping to understand the groundwater recharge potential of the watersheds.
- Water quality data for all seasons for two years to assess the sustainability of water resources.
- Discharge and rainfall data for critical springs collected by Para workers appointed in each watershed.
- Porosity maps prepared based on the data collected on Chal-Khal, soil infiltration, and soil mapping to identify areas with higher recharge potential.

It is essential to collect all of these primary data to have a comprehensive understanding of the hydrogeological and social characteristics of the watersheds and to develop effective management strategies for sustainable water resource management.

3.4 Details of Field Survey conducted, if any

- Watershed survey: A survey of six watersheds, including Bareth, Malan, Ghurdauri, Kaddukhal, Kotigad, and Moldhar, was conducted to assess the hydrogeological and social characteristics of each watershed.
- Spring inventory: Twenty springs were inventoried in each watershed to identify critical springs for which water user groups were formed.
- Hydrogeological survey: Detailed geological mapping and cross-sections were prepared for each watershed, and recharge areas were identified. Engineering measures were designed based on these data.
- Social survey: Water user groups were formed for critical springs, and community workshops were organized to share experiences and challenges faced in the field.
- Data collection: Data on Chal-Khal, soil infiltration, and soil mapping were collected in each watershed (100 data points in each watershed). Water quality data for all seasons for two years was also collected.
- Engineering measures: Trenches and plantations were implemented in the recharge area of the spring in collaboration with the community.

- Para worker appointment: Six Para workers were appointed in each watershed to collect discharge and rainfall data for critical springs regularly.

These details suggest that the field survey was comprehensive and involved a range of activities to assess the hydrogeological and social characteristics of the watersheds and develop effective management strategies for sustainable water resource management.

3.5 Strategic Planning for each activity with time-frame

Activities	Strategic Planning
To characterize hydrologic conditions of the springs during different seasons.	The Bi-weekly spring discharge measurement are being made to Characterize the monthly and seasonal hydrology of the springs.
To evaluate spring flow response from differing aquifer geometries and geophysical methods.	The data related to lithology, fracture, slope and landforms characteristics and their relationship with spring discharge were used to understand and evaluate the hydrological responses of aquifer characteristics/geometrics.
To revive dying springs in Himalayas: groundwater recharge using geo-hydrology technology	The infiltration and soil characteristics data together with data collected in above (in 2) have helped in delineating the potential recharge area where the soil and water conservation measures were applied for the revival of the springs.
To develop a spring shed management protocol for maintenance and protection of springs with the help of local communities and other stakeholders	Social survey (PRA) conducted in every village of selected watersheds to understand the demography of village, it also helps to calculate the water demand of community. To develop a spring shed management protocol, water user groups (WUG) were formed for all 30 springs. A water user group is a general body that comprise of adult community members from all households that are directly depend on the spring to meet their water demands and are also responsible to take care of source of water.
To develop a database for springs, which includes classified maps, geological maps and record of spring discharge in different seasons.	For every watershed detailed geological mapping has done. The project took traverse along the entire watersheds and they did lithological, feature mapping, and created a geological map. To keep a record of discharge of the spring, village Para workers has been deputed who monitor the discharge of spring on weekly basis.

Identification of indicator plant species for locating spring shed and prescription of engineering and vegetative measures best suited for water harvesting.	While doing the primary inventory of spring, it is seen that what kind of trees and plants are there in that area, and its detailed information is collected from the community. Recharge area identified after hydro geological survey. After identifying the recharge area engineering and vegetative measures has proposed for water harvesting.
Identify and restore the Time-tested Chal/khal and develop the training needs of Village/Community for their sustained maintenance.	Identification of pre-existing chal-khal in recharge has done for all watersheds. The Community was trained on spring conservation and its maintenance during the field visit of the project investigators and collaborators.

4 KEY FINDINGS AND RESULTS

4.1 Major Activities/ Findings

A field survey of the study region and surrounding areas was carried out. Demarcation of the spring catchment area was performed with reconnaissance of surrounding landuse landcover falling. Information about the water related issues in the village, and to assess the dependence of local stakehol ders on the spring during lean period water crisis was evaluated. For analyzing the hydraulic properties as well as the soil texture, soil samples of different landuse/landcover classes like agricultural, barren and forest land were collected.

Engineering measures were carried out in six critical springsheds. Geological and engineering survey were carried out in the recharge area of these springs, and then recharge area has been identified. These areas were abandoned agriculture land; now people are not doing agriculture practices in these fields, they only make use of the grass from these fields.

After discussion with community it was decided that, the toe trenches will be made in abandoned agriculture land, along with grass saplings and tree plantation. Toe trenches will help to retain the soil moisture and increase the discharge of springs. Vegetative measures will increase the biomass and reduce the soil erosion. Supporting documents are attached.

Climate change projection (for the near-future) analyses were conducted for the State of Uttarakhand. The issue of water and rejuvenation of springs in a changing climate were analysed and provided in the appendix.

4.2 Key Results

- Demography of the villages
- Spring inventory
- Land Use Land Change of the catchment/recharge area
- Hydrogeological maps of the selected springsheds
- Geology of the selected springsheds
- Soil characteristics of the springshed regions
- Climate projection analyses for Uttarakhand for the near-future

4.3 Conclusion of the study

Managing water in 21st century in complex sloping landscape of middle Himalaya will need more holistic understanding of soil, hydrogeology, landuse, forest, hydrometeorology and the recent changes including climate change. More so, the interaction between soil–water and landscape–soil-hydrology relationships should be studied in greater details. The present study highlights that the near-surface, topsoil and the sub-soil are showing very low hydraulic conductivity which indicate a high runoff potential of the soil formation in permanent fallow land which dominates the landscape. The rainfall intensity measurements in close proximity from the adjoining watershed of western Nayar show rainfall intensity of less than 2.5 mm/hour (light intensity) dominates the monsoon rainfall event and likely to cause overland flow in most of the rainfall event under saturated condition of soil. Agricultural land abandonment with livestock trampling may have caused the compaction of soil in recent times and hence require appropriate land management.

This study in the Garhwal region is a crucial step towards mitigating the effects of climate change in the area. The project, which involves restoring the natural springs, can have a significant impact on the local environment, economy, and community. The initiative also helps to raise awareness about the need for sustainable and environmentally-friendly practices. However, it is essential to note that this project must be part of a larger effort to address the impact of climate change in the region. The Garhwal region is vulnerable to natural disasters such as floods, landslides, and droughts, which are becoming more frequent and severe due to climate change. Therefore, it is crucial to implement other measures such as afforestation, soil conservation, and waste management to ensure long-term sustainability. It is a promising initiative that can serve as a model for other regions affected by climate change. The project provides hope for the community and future generations, and it is imperative to continue supporting and expanding such initiatives to create a sustainable future for all.

5 OVERALL ACHIEVEMENTS –

5.1 Achievement on Project Objectives/ Target Deliverables

S. No.	Objectives	Achievements
1	To characterize hydrologic conditions of the springs during different seasons.	• Discharge monitoring and measurement for 30 critical springs was done in 6 watersheds.
2	To evaluate spring flow response from differing aquifer geometries and geophysical methods.	• Detailed geological mapping and cross section were prepared for each watershed.
3	To revive dying springs in Himalayas: groundwater recharge using geo-hydrology technology	• Recharge areas identified. • Prepared porosity maps based on data. • Engineering measures carried out in the recharge area of spring in collaboration with the community. • Policy guidelines for parameters related to spring rejuvenation and biodiversity were prepared.
4	To develop a spring shed management protocol for maintenance and protection of springs with the help of local communities and other stakeholders	• Spring shed management protocol has been prepared.
5	To develop a database for springs, which includes classified maps, geological maps and record of spring discharge in different seasons	• Geological maps prepared for 6 watersheds.

6	Identification of indicator plant species for locating spring shed and prescription of engineering and vegetative measures best suited for water harvesting.	• Indicator plant species were identified for 6 watersheds and database prepared
7	Identify and restore the Time-tested Chal/khal and develop the training needs of Village/Community for their sustained maintenance	• Spring flow database forPauri Garhwal's springs (Bareth, Malan, Ghurdauri watersheds), and Tehri Garhwal's springs (Moldhar, Kotigad and Kaddukhal watersheds) have prepared.

5.2 Interventions

Technological interventions:

- Rainwater Harvesting: Site-specific methods have been implemented for rainwater harvesting to replenish the groundwater and recharge the springs. Staggered contour trenches were constructed for this purpose.
- Satellite Imagery: High-resolution satellite imagery were used to identify the areas that need immediate attention for spring rejuvenation. This technology may also be used to monitor the progress of the rejuvenation project over time.
- Plantation of grasses and tree saplings were done in the field after identifying the site-specific species.
- Groundwater Recharge: Artificial recharge techniques such as injection wells and recharge pits were done in the field. These techniques can increase the groundwater table and improve the flow of water in the springs.

Social interventions:

- Community Participation: Community participation is crucial for the successful field implementation of any rejuvenation project. The local communities were involved in the planning, implementation, and monitoring of the project. This involvement was achieved through meetings, workshops, and awareness campaigns.

5.3 On-field Demonstration and Value-addition of Products

Community workshops were conducted in Chamba (Tehri Garhwal) and Ghumkhal (Pauri Garhwal). The objective of the workshops was to bring the community and supporters together to understand roles of each other. 40 Members of Water User Groups and para workers from Tehri and Pauri watershed participated in these workshops which provided platforms to the community members to share their experiences and challenges while spring shed treatment activities for their respective springs. Find below the agenda and other details of the workshops.

Community workshop at Pauri Garhwal

Community workshop at Tehri Garhwal

5.4 Green Skills developed in State/ UT

The local community were apprised on the importance of sustainable land use and agriculture during the awareness programs. Training on water management skills such as rainwater harvesting and water conservation was done to ensure sustainable use of water resources in their localities. They were also appraised of the importance of recycling and composting waste. Awareness session were also done on forest conservation, wildlife management and biodiversity conservation.

5.5 Addressing Cross-cutting Issues

Effective and judicious management of water is crucial in the Grahwal region in a changing climate with abrupt rainfall spells. This includes managing water use and allocation, monitoring water quality and protecting water sources from pollution. The importance of water management was discussed during the interaction programs with the local community and measures were taken with their involvement. The importance of protecting the natural habitats, managing invasive species and promoting sustainable land use practices were discussed in detail during the awareness programs. Local communities were involved in the planning and implementation of the field activities and their needs and concerns were taken into account. Women participation was there in the field activities as they bear the brunt of water scarcity and they were involved in the decision-making processes to ensure that their needs and concerns were addressed. Climate change is very likely to have a significant impact in the water availability and quality in the Garhwal region. Climate change projection analyses were carried out for the near future for the State of Uttarakhand.

PROJECT'S IMPACTS IN IHR –

5.6 Socio-Economic impact

The water availability in the selected springshed regions have shown increasing tendencies during the period. This will have a positive impact on agriculture, livestock and water-dependent livelihoods. This can lead to diversification of livelihoods like ecotourism and organic farming. Improving the access to clean drinking water will reduce the incidence of waterborne diseases which will reduce healthcare cost and increase productivity. New employment opportunities might come up if the activities performed are sustained with local community involvement. The issue of migration to urban areas may be resolved to some extent by the resurgence of the local economy.

5.7 Impact on of Natural Resources/ Environment

The project implementation has improved the quantity and quality of water in the region. Restoration of chal in the catchment was found to have a significant impact in containing the fire as the ground had remained wet for longer period. This will have a positive impact on the environment and ecosystems and can lead to improved biodiversity, increased vegetation cover, and reduced soil erosion. Improved soil quality, reduction in soil erosion and increased growth of vegetation may be expected with the local community participation in maintaining the recharge areas of the springsheds. This will increase carbon sequestration and contribute to regional climate change mitigation. This will also reduce the impact of deforestation and forest degradation to some extent in the region. Degraded habitats may be restored through sustainable land use practices.

5.8 Conservation of Biodiversity/ Land Rehabilitation in IHR

The increased availability of water will help restore degraded land by promoting sustainable land use practices. This can help improve soil quality, increase vegetation cover and promote the growth of local ecosystems. This may help protect endangered species and ensure long-term sustainability of natural resources of the region.

5.9 Developing Mountain Infrastructures

Being important source of water, minerals, forest products/medicinal plants, recreation/adventure including tourism, Himalayan mountains are fragile in nature. Development of infrastructure should thus keep in view the sustainability of water resources, biological diversity, compatible agriculture and waste management. Roads have caused great damage to the stability of mountains, made disappearance of water in the springs. Special attention is desired in this regard while aligning.

5.10 Strengthening Networking in State/ UT

Strengthening the network is important towards ensuring the long-term sustainability of the region's natural resources and ecosystems. Building collaborative partnerships between government agencies, non-governmental organizations, local communities, and other stakeholders can help strengthen the network.

For the field implementation of the project, research institutes and NGOs who have expertise in the Garhwal region were involved. People’s Science Institute, Dehradun and Uttarakhand Jal Sansthan were participated during the field implementation phase of the project. GBPNIHESD, Almora was the partner institute in the project. These partnerships helped ensure the effective coordination of efforts, promote knowledge sharing, and foster community engagement. Knowledge sharing is crucial in effective implementation of the project. Building the capacity of local communities and other stakeholders is important and the networking with institutions and NGOs with local expertise helped in fulfilling the objectives of the project. A strong network is important in effective communication and outreach strategies.

6 EXIT STRATEGY AND SUSTAINABILITY –

6.1 Utility of project findings

The findings of the project can be used to inform policy decisions related to management of natural resources and water conservation in the Garhwal region. Policymakers can use the findings to identify effective strategies for sustainable landuse practices, water management, and conservation efforts.

The project findings can also be used to guide future implementation of similar projects in the region. The project findings can help identify areas where additional research is needed or where certain interventions are specifically effective. It will also be useful in building local capacity and knowledge among communities and other stakeholders. The project can help promote the adoption of sustainable land use practices, water management techniques and conservation efforts that can improve the long-term sustainability of Garhwal region. The project findings will be useful to raise awareness among local communities, policymakers and other stakeholders on the importance of conservation of natural resources and sustainable development. Sharing the project findings will help the stakeholders can build support for continued efforts to protect the regional ecosystem. The findings of the project can contribute to global knowledge on water conservation, natural resources management and sustainable development particularly in areas facing similar environmental challenges.

6.2 Other Gap Areas

Even though efforts are put in to address the major issues of water availability, conservation and management, there may still be some gap areas that require attention. Ensuring effective and meaningful participation of all relevant stakeholders, including local communities, women, marginalized groups is crucial for long-term sustainability of the water management efforts. There might be a need to enhance stakeholder engagement and participation in decision-making processes to ensure that their perspectives and needs are adequately addressed. While the project may focus on immediate interventions for spring rejuvenation, there is a need to emphasize long-term sustainability. This can involve strategies to ensure the continued maintenance and management of rejuvenated springs, as well as the adoption of sustainable practices by local communities even after the project's completion. Robust monitoring and evaluation mechanisms are essential to assess the effectiveness of the project interventions and to track progress towards project goals. Adapting to the changing climate is important in reducing the vulnerability of the local community. Securing adequate financial resources for the implementation and scaling up of the spring rejuvenation project is critical. Identifying potential funding sources, developing sustainable financing mechanisms, and mobilizing resources from both public and private sectors can help address the gap in financial sustainability.

6.3 Major Recommendations/ Way Forward

- Ensure meaningful engagement and participation of all relevant stakeholders, including local communities, women, marginalized groups, and indigenous communities. Incorporate their perspectives, needs, and traditional knowledge into decision-making processes.
- Develop a comprehensive long-term sustainability plan for the rejuvenated springs, including strategies for their continued maintenance, monitoring, and management engaging local communities specially women power in the strict protection of springshed/micro-springshed including stewardship of the springs to ensure their long-term sustainability.
- Incorporate climate change adaptation measures into the project design and implementation. Assess the vulnerability of springs to climate change impacts and develop adaptive strategies to safeguard water resources in the face of changing climate conditions.
- Establish a robust monitoring and evaluation framework to track the progress and impact of the project. Regularly assess the effectiveness of interventions, collect relevant data, and use the findings to make informed decisions and adjustments to project activities.
- Develop a comprehensive knowledge dissemination strategy to share project findings, best practices, and lessons learned with stakeholders. Conduct capacity-building programs and workshops to enhance the knowledge and skills of local communities, government agencies, and other stakeholders involved in spring rejuvenation efforts.

- Identify and explore potential funding sources, including government grants, public-private partnerships, and international funding mechanisms, to ensure sustainable financing for the project. Develop innovative financing mechanisms and leverage resources from multiple sectors to support the implementation and scaling up of the project.
- Foster collaboration and partnerships with relevant stakeholders, including government agencies, non-governmental organizations, research institutions, and local communities. Collaborative efforts can enhance the project's impact, leverage expertise, and share resources and knowledge for a more comprehensive approach to spring rejuvenation.
- Advocate for the integration of spring rejuvenation principles and approaches into relevant policies, regulations, and development plans at the regional and national levels. Engage with policymakers and advocate for supportive frameworks that promote sustainable water management and natural resource conservation.

6.4 Replication/ Upscaling/ Post-Project Sustainability of Interventions

Documentation of the successful interventions, lessons learned, and best practices from the project is important. This information should be disseminated widely through reports, case studies, workshops, and conferences. Sharing knowledge and experiences will facilitate replication of successful approaches in other areas. Promote community ownership and active participation in the spring rejuvenation interventions is crucial. Empowerment of local communities to take ownership of the rejuvenated springs, including their maintenance, monitoring, and management will be highly useful for long-term sustainability. Encourage the formation of community-based organizations and user groups to sustain the interventions are also important.

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Appendix 1 – Details of Technical Activities

Geology of the Bareth Watershed

Bareth Watershed lies in the Pauri Garhwal district. The rocks of this district belong to the Lesser Himalayan Zone and are characterized by superimposed thrust sheets mainly North Almora Thrust (NAT) in the north-eastern part. The thrust is traversed by two faults trending NE-SW and NNE-SSW namely Burkot and Koteshwar faults. The geological set up is very complex due to the repeated tectonic disturbances caused by different orogenic cycles. The rocks present in the watershed includes Phyllite, Slate, Quartzites with schist of Saryu formation of Almora Group at some places.

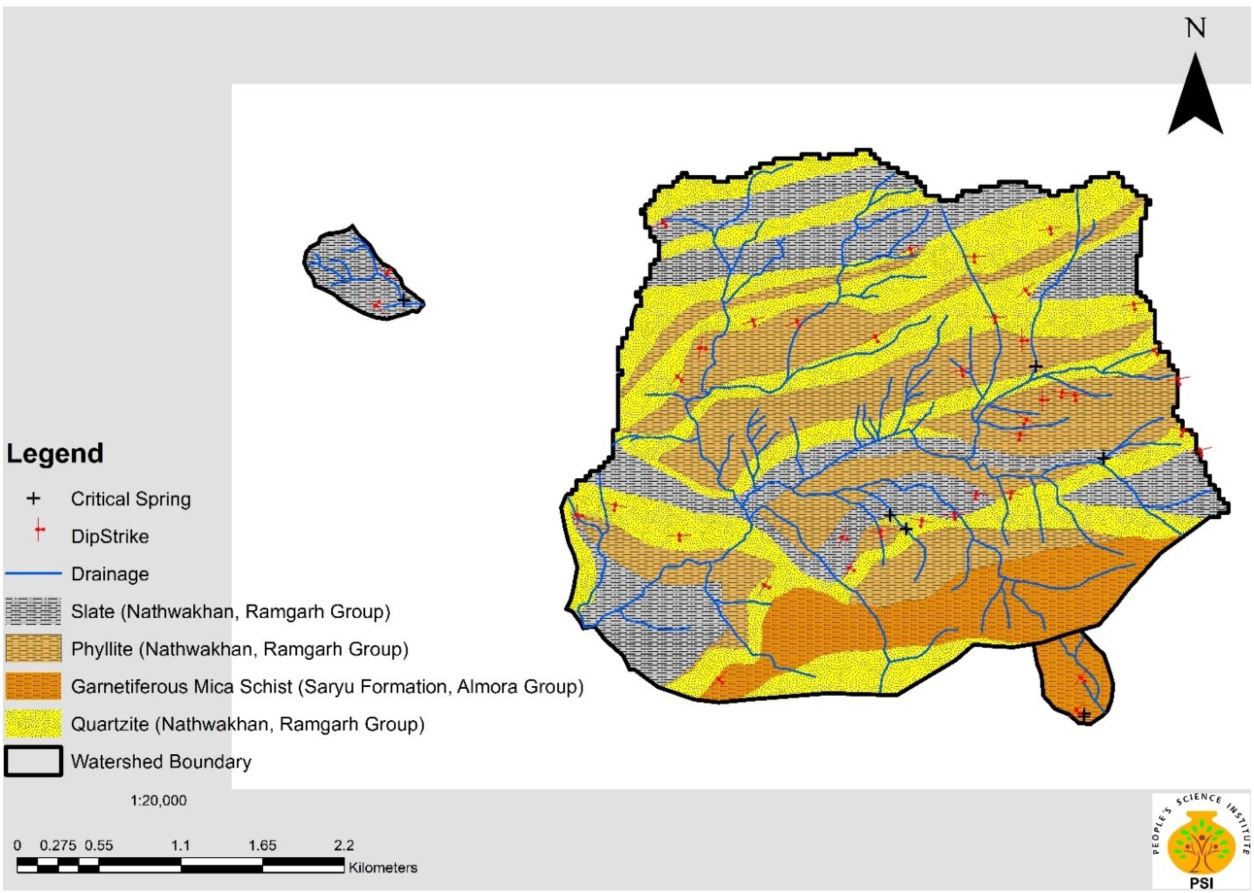


Figure 1: Geological map of the Bareth watershed.

STRUCTURE: Table 1shows that the area has two plunge values in the North-East and South-East directions with their amounts ranging from 10^0-50^0 but most commonly the beds dip in the South-Eastern direction therefore having a strike in NE-SW direction. Bareth watershed has highly folded anticlinal folds with 4 prominent set of fractures in NE, SE, NW and SW directions therefore controlling the underground movement of water.

Table 1: Fracture- Joints data of Bareth watershed

Sl. No.	Location		Elevation(m)	Bedding Plane		Fracture								Rock Type
	Latitude	Longitude		Dip Direction(N)	Amount	F1(N)	Amount	F2(N)	Amount	F3(N)	Amount	F4(N)	Amount	
1	30.00737	78.55817	1325	188	10	10	75	-	-	188	10	280	81	slaty phyllite
2	30.00585	78.55604	1307	210	31	20	70	-	-	210	31	285	85	slaty phyllite quartz veins
3	30.00484	78.55563	1300	190	29	20	68	-	-	190	29	290	80	schist, slaty phyllite
4	30.00129	78.55509	1269	190	30	30	80	120	78	190	30	330	55	quartzite, slaty phyllite
5	30.00126	78.55298	1255	190	25	10	70	-	-	190	25	280	75	slate with 2m thick quartz vein
6	29.99989	78.55168	1239	170	20	35	68	160	40	-	-	330	72	slate, quartzite
7	29.99962	78.54967	1227	190	25	40	65	-	-	190	25	335	70	quartzite
8	29.99886	78.54722	1203	175	30	60	80	-	-	175	30	310	78	phyllite
9	29.99984	78.54898	1201	-	-	-	-	-	-	-	-	-	-	slate, quartzite
10	30.00041	78.54879	1176	150	25			150	25	220	65	310	50	phyllite
11	30.00171	78.54937	1157	-	-	-	-	-	-	-	-	-	-	slate
12	30.01327	78.55614	1381	140	50	-	-	140	50	220	78	310	75	quartzite
13	30.01161	78.55076	1439	-	-	-	-	-	-	-	-	-	-	weathered quartzite
14	30.01186	78.55412	1458	180	10	10	72	-	-	180	10	280	80	quartzite
15	30.01551	78.55287	1555	180	35	-	-	-	-	-	-	-	-	highly weathered quartzite
16	30.01714	78.55748	1558	170	30	80	78	170	30	235	52	340	67	quartzite
17	30.00383	78.56708	1644	165	25	80	78	165	25	235	52	340	67	quartzite with thin slate intercalations
18	30.00546	78.56675	1639	200	25	70	68	-	-	200	25	340	70	slate, quartzite
19	30.00811	78.56562	1619	170	31	-	-	170	31	-	-	-	-	sandy slate
20	30.00962	78.56392	1613	140	40	60	70	140	40	-	-	330	57	quartzite
21	30.01258	78.56255	1605	170	20	-	-	170	20	250	65	320	70	slate, quartzite
22	29.99825	78.54521	1226	110	10	-	-	140	60	230	55	-	-	slate
23	29.99642	78.54559	1217	120	15	-	-	120	15	240	68	330	69	slate, quartzite
24	29.99537	78.54046	1212	120	20	-	-	120	20	240	68	330	65	quartzite with phyllite interbeddings and schist underneath
25	29.98972	78.53759	1260	135	25	-	-	135	25	190	68	280	70	quartzite with phyllite interbedding
26	30.00658	78.55747	1367	-	-	-	-	-	-	-	-	-	-	phyllite, schist, quartz veins
27	30.00708	78.55899	1397	175	15	-	-	175	15	260	88	350	78	phyllite with thin schist beds and veins of quartz
28	30.01016	78.55626	1328	40	16	40	16	-	-	190	65	320	68	slate, phyllite, quartzite
29	30.00859	78.55214	1314	170	45	40	80	170	45	-	-	315	72	slaty phyllite
30	30.01049	78.54697	1290	150	30	45	63	150	30	220	68	310	57	quartzite with thin chips of phyllite
31	30.01143	78.54223	1248	155	35	45	65	155	35	220	58	300	61	slaty phyllite with thick quartz vein above it
32	30.01152	78.53952	1184	160	32	45	65	160	32	220	57	300	60	quartzite with thin phyllite beds
33	30.00969	78.53671	1144	100	21	-	-	100	21	180	78	280	75	slate, phyllite
34	30.00801	78.53512	1102	130	10	30	80	130	10	220	58	310	65	quartzite
35	29.98067	78.54381	1434	100	21	-	-	100	21	180	78	280	75	schist at bottom, quartzite on top with chips of phyllite
36	29.98285	78.54471	1460	130	10	30	79	130	10	220	58	310	62	slate, phyllite
37	29.98581	78.54489	1461	125	10	30	80	125	10	220	56	310	60	quartzite, slate
38	29.98656	78.54492	1478	120	10	-	-	-	-	-	-	-	-	quartzite, schist
39	29.98701	78.54569	1459	-	-	-	-	-	-	-	-	-	-	schist, quartzite
40	29.98702	78.54647	1452	120	21	30	80	120	21	220	58	310	65	schist
41	29.98768	78.55433	1481	-	-	-	-	-	-	-	-	-	-	schist, quartzite
42	29.98785	78.55924	1515	135	30	-	-	-	-	-	-	-	-	schist

43	29.98979	78.55953	1527	130	20	-	-	-	-	-	-	-	-	highly weathered and folded schist
44	29.98919	78.56643	1530	180	15	-	-	170	80	260	65	335	78	schist
45	29.99478	78.56764	1564	160	32	-	-	-	-	-	-	-	-	schist
46	29.99723	78.56887	1583	180	40	55	62	140	80	180	40	320	78	schist, quartzite
47	29.99564	78.57276	1620	170	20	-	-	-	-	-	-	-	-	phyllite
48	29.99771	78.57136	1676	170	30	-	-	-	-	-	-	-	-	phyllite, quartzite
50	30.01367	78.54964	1541	-	-	-	-	-	-	-	-	-	-	quartzite
51	30.01585	78.54905	1524	160	25	-	-	130	78	220	59	-	-	slate, quartzite
52	30.01744	78.53414	1478	150	30									quartzite, slate
53	30.01441	78.51805	1422	50	28	50	28	160	68					Slate
54	30.01248	78.51738	1413	50	30	50	30	170	71	260	68	345	50	Slate
56	30.01317	78.52978	1289	120	35	-	-	160	78	250	70	330	68	Quartzite
57	30.01187	78.52749	1251	40	10	40	10	-	-	250	52	340	71	Slate
58	30.01016	78.53028	1249	130	35	-	-	130	35	250	65	340	70	Quartzite
59	30.00449	78.52851	1165	60	25	-	-	-	-	-	-	-	-	Quartzite, Slate
60	30.00123	78.52806	1176	58	40	58	40	-	-	230	55	320	67	Quartzite
61	30.00057	78.53111	1442	190	30	-	-	-	-	250	68	340	70	Quartzite
62	29.99958	78.52931	1104	50	35	50	35	130	67	220	50	-	-	Quartzite, Slate
63	29.99865	78.53502	1054	178	30	-	-	178	30	260	65	350	55	Quartzite
64	29.99931	78.53664	1044	-	-	-	-	-	-	-	-	-	-	Quartzite

Influence of rocks and structure on groundwater:

The metamorphics are generally characterized by secondary porosity and permeability due to weathering and fracturing of rocks. Therefore, groundwater movement occurs mainly due to secondary porosity and permeability present in these rocks.The springs observed in this region were mostly depression springs and fracture springs associated with old landslide deposits and fracture and weathered zones (Valdiya and Bartarya, 1991). The fractures and joints serve as the conduit for subsurface water.

Geology of the Ghurdauri watershed

Ghurdauri watershed located near Pauri city in Pauri-Garhwal district belongs to the Lesser Himalayan Zone and is characterized by superimposed by mainly North Almora Thrust (NAT) in the north-eastern part. The thrust is traversed by two faults trending NE-SW and NNE-SSW namely Burkot and Koteshwar faults. The trend of NAT is NW-SE, dipping at 40°-50° towards SW. Rocks of Ghurdauri watershed belong to Chandpur formation of Jaunsar Group of Precambrian Age.

The folds of the region are thought to be genetically associated with thrusts and shear zones. Thin bands of Quartzite and Slate of grey, greyish green are exposed in SE part of the watershed. The greyish green slate frequently shows stains of concentric reddish brown oxidation rings on the surface.

Geology of the Area

Jaunsar Group (Lower Palaeozoic to Proterozoic)	Nagthat – Berinag Formation **Chandpur Formation** Mandhali Formation	Quartzites interbedded with slates and phyllites **Slates and Phyllite** Carbonaceous phyllite, slate, and minor limestone
Tejam Group (Proterozoic)	Deoban Formation	White and light pink dolomites
Damtha Group (Proterozoic)	Rautgara Formation	Quartzites interbedded with sublitharenites, slates and metavolcanics.

All the three formations of Jaunsar i.e., Mandhali, Chandpur and Nagthat are located to the east of Chakrata in Yamuna valley. Mandhali limestone is partly equivalent to Deoban (Tejam). Chandpur slates and phyllites sometimes with bands of quartzites are exposed in Aglar valley in Tehri, around Deoprayag in Ganga and Pauri-Ghurdauri Road section in Garhwal and also in the lower reaches of Machhlad and Purvi Nayar. These phyllites are also locally known as Pauri Phyllites. These phyllites are overlain by thick Nagthat quartzites which are best exposed in Nagthat hill on the right bank of Yamuna River. High mica content in Phyllites near Kanda was observed making them super glittery whereas at some places high chlorite content was observed giving them the green colour.

Structure: Ghurdauri watershed has highly folded anticlinal mountains with 3-set of fractures in SE, SW and NW directions. Rocks present are phyllite with thin lenses of quartzite at some places. Two folds plunges in northeast and southeast directions with amount ranging from 10°-70° but mostly the beds dip towards North-East. Rock type present in the watershed is mostly Phyllite with variation in its grade.

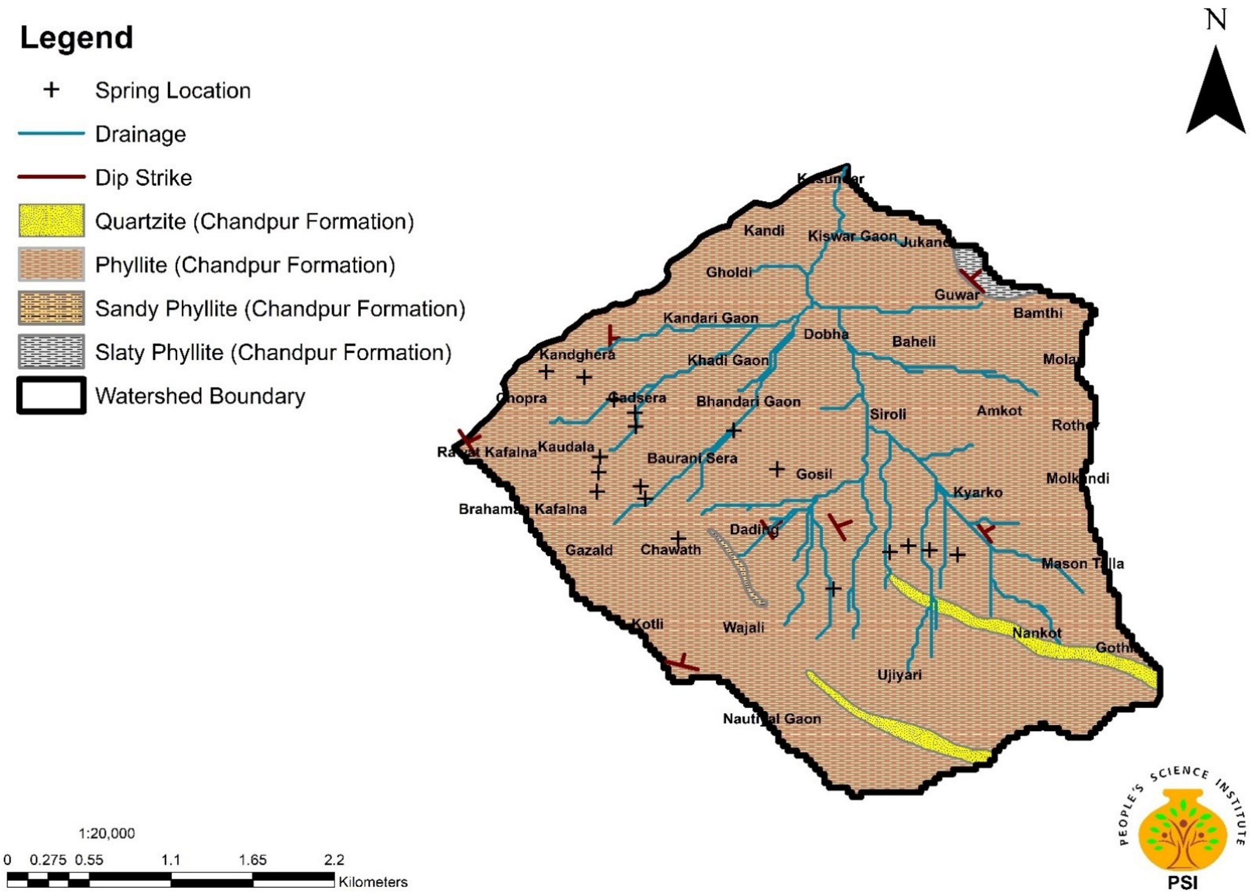


Figure 2. Geological map of the Ghurdauri Watershed.

Influence of rock type on groundwater:

The phyllites are characterized by secondary porosity and permeability due to weathering and fracturing of rocks. Therefore, groundwater movement occurs mainly along secondary porosity and permeability present in the phyllite. The springs observed in this region were mostly depression and fracture springs associated with old landslide deposits and weathered zones (Valdiya and Bartarya, 1991). The fractures and joints serve as the conduit for subsurface water.

Table 2: Showing attitude of fractures in the Ghurdauri watershed

Location		**Bedding Plane**		**Fracture**			**Rock Type**
Longitude	**Latitude**	**Dip direction**	**Amount**	**F1**	**F2**	**F3**	
78º46'03.73"	30º09'28.52"	N70º	56º	N200º,31º	N105º,86º	N340º,74º	Phyllite
78º45'58.32"	30º09'32.46"	N60º	25º	N220º,68º	-	-	Phyllite
78º43'44.80"	30º10'4.62"	N50º	25º	N205º,70º	N110º,85º	-	Phyllite
78º43'11.18"	30º10'45.91"	N100º	75º	-		-	Phyllite
78º43'22.83"	30º10'58.02"	-	-	-	-	-	Phyllite
78º43'6.71"	30º10'58.02"	N90º	70º	-	-	N360º,50º	Phyllite
78º42'12.66"	30º11'33.57"	-	-	-	-	-	Phyllite
78º42'23.46"	30º11'39.39"	N100º	25º	N270º,58º	-	N190º,65º	Phyllite
79º42'59.29"	30º11'45.36"	N40º	30º	N190º,	-	N120º,80º	Slaty Phyllite
78º43'7.91	30º11'58.66"	N50º	55º	N270º,20º	N145º,83º	-	Phyllite
78º43'1.85"	30º12'52.83"	-	-	-	-	-	Phyllite
78º44'00.21"	30º10'04.25"	N50º	20º	N10º,75º	N135º,78º	N30º,80º	Phyllite
78º45'53.90"	30º9'48.93"	N35º	78º	N180º,35º	N120º,61º	N120º,61º	Phyllite

78º45'25.67"	30º10'6.99"	N30º	10º	N90º,52º	N40º,78º	-	Phyllite
78º45'24.61"	30º10'9.82"	N55º	70º	N90º,53º	-	N360º,43º	Sandy Phyllite
78º45'4.38"	30º10'18.98"	N20º	15º	-	-	-	Sandy Phyllite
78º45'00.53"	30º10'57.63"	N15º	10º	-	-	-	Phyllite
78º44'55.85"	30º10.59.86"	N30º	40º	-		-	Phyllite
78º44'49.84"	30º11'8.10"	N20º	17º	-	-	-	Phyllite
78º44'29.17"	30º10'59.03"	N30º	35º	N190º,45º		-	Slaty Phyllite
78º44'29.17"	30º11'17.90"	-	-	-	-	-	Phyllite
78º45'4.23"	30º11'37.10"	N45º	30º	-	-	-	Phyllite
78º44'56.27"	30º11'45.52"	N90º	30º	N250º,55º		N40º,55º	Phyllite
78º44'35.41"	30º10'36.74"			-	-	-	Phyllite
78º44'31.46"	30º10'3.50"	N50º	45º	N290º,85º	N160º,75º	N110º,83º	Phyllite
78º44'53.24"	30º10'30.26"	N20º	35º	N220º,86º	-	N310º,67º	Phyllite
78º44'45.25"	30º10'13.39"	-	-	-	N60º,70º	N330º,86º	Phyllite
78º44'15.50"	30º9'51.62"	-	-	-	-	-	Quartzite boulder
78º43'49.86"	30º9'52.05"	N45º	41º	N190º,53º	N120º,65º	N30º,70º	Phyllite
78º43'45.65"	30º9'55.80	N115º	47º	-	N15º,87º	N310º,86º	Phyllite
78º43'39.51"	30º9'56.74"	-	-	-	-	-	Sandy Phyllite
78º71'98.25"	30º16'9.405"	-	-	-	-	-	colluvium with patches of phyllite
78º41'27.52"	30º11'25.93"	N50º	12º	N120º,73º	-	N45º,74º	Phyllite
78º41'30.15"	30º11'30.00"	-	-	-	-	-	Phyllite
78º41'20.84"	30º11'15.2"	N125º	30º	N220º,42º	N30º,53º	N110º,80º	Phyllite
78º41'30.19"	30º11'7.96"	N120º	10º	-	N80º,70º	-	Phyllite
78º41'51.71"	30º10'48.64"	N65º	50º	N175º,65º	-	-	Phyllite
78º42'17.16"	30º10'38.66"	N110º	60º	N220º,65º	-	N295º,83º	Phyllite
78º42'39.67"	30º10'24.50"	N50º	45º	-	-	-	Phyllite
78º42'58.19"	30º10'1.36"	N55º	61º	N273º,70º	N90º,70º	N360º,70º	Phyllite
78º43'25.07"	30º9'35.47"	N15º	25º	N215º,85º	N15º,25º	-	Phyllite
78º44'13.18"	30º09'21.40"	-	-	-	-	-	Quartzite boulders
78º45'7.76"	30º9'41.10"	N70º	25º	-	-	-	Quartzite
78º45'15.63"	30º9'43.33"	N40º	15º	N230º,60º	N100º,52º	-	Phyllite

Geology of the Kaddukhal Watershed

This area is characterised by rocks of Lesser Himalaya and Central Himalaya. The Lesser Himalaya occupies major part of the Tehri district and comprises of rocks of different groups such as Jaunsar Group, Blaini-Krol Group and Tal Group.

The rocks present in the watershed mainly belongs to Tal Formation of Mussoorie Group underlain by the rocks of Krol Group. The Tal in the Mussoorie Synform can be divided into the Lower Tal and Upper Tal. For the Lower Tal, there are four subdivisions: the Chert, Argillaceous, Arenaceous and Calcareous Units. The basal black shale succession with sandy limestone represents a depositional environment of a protected lagoon and siltstone in mud flat or tidal environment.

The Upper Tal can be subdivided into lower quartzitic sequence and upper thick calcareous sequence containing abundant fragmentary shells of bivalves, etc. The Phulchatti quartzite succession represents the deposits of a shoal environment, while the uppermost shell limestone sequence indicates an increasing energy of the shallow tidal sea, and a marine transgression in the Cretaceous.

The rocks in the area have two dips in the North-East and South-East directions but most commonly the beds dip in the North-Eastern direction. Rocks commonly present are Quartzites, Slates, Limestones of Tal Formation.

The rocks in the area have two dips in the North-East and South-East directions but most commonly the beds dip in the North-Eastern direction. Rocks commonly present are Quartzites, Slates, Limestones of Tal Formation.

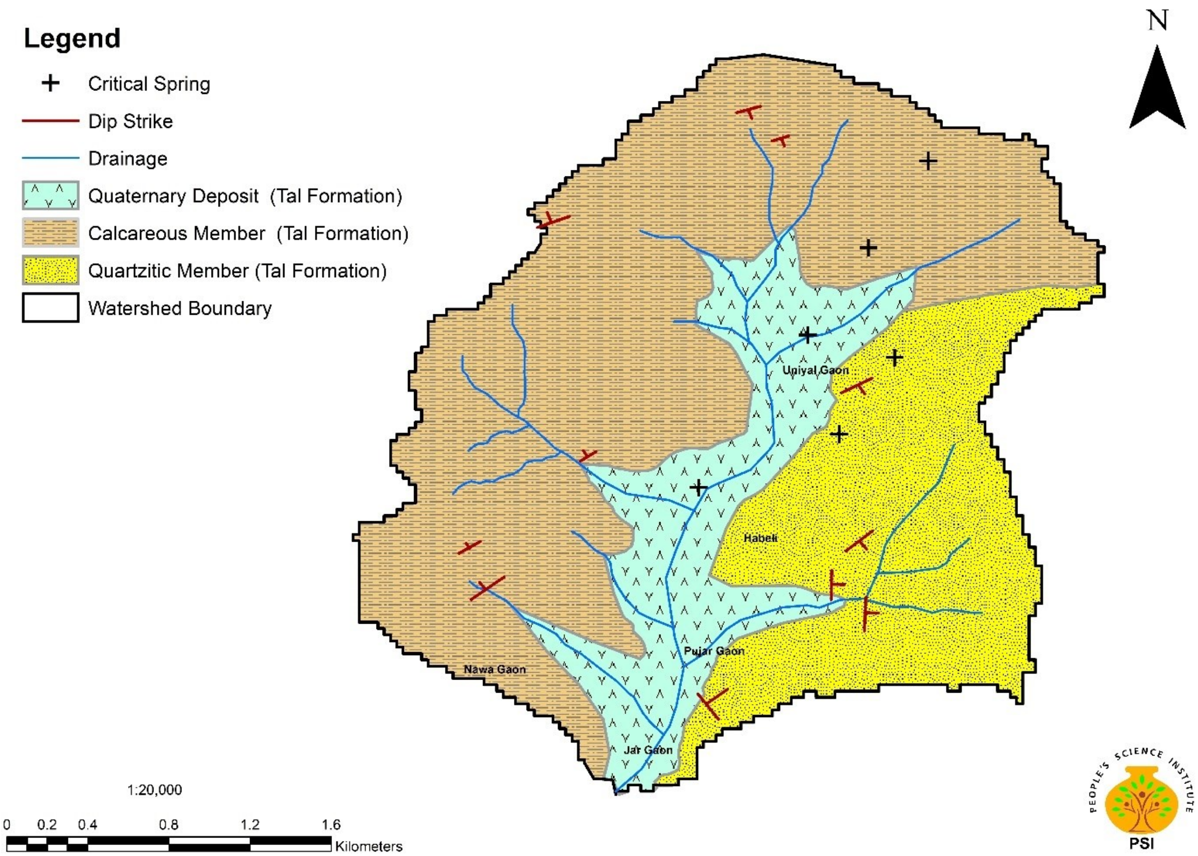


Figure 3. Geological map of Kaddukhal Watershed

STRUCTURE: Kaddukhal watershed has highly folded anticlinal mountains with 4 set of fractures in NE, SE, NW and SW directions (Table 1) therefore controlling the underground movement of water.

Table 3: Fractures sets in Kaddukhal watershed.

S.No.	Longitude (D M S)	Latitude (D M S)	Elevation (in m)	Rock type/Dip D/Angle	Joints patterns (Direction/Angle)	
	N	E			1	2
1	30 24 13.39	78 17 22.86	2317	Limestone/SSE/40	WNW/80	E/70
2	30 23 56.37	78 16 49.68	2475	Limestone/NW/40	WNW/80	SSE/75
3	30 22 56.94	78 16 41.15	1889	Limestone/NW/40	NE/80	SSE/70
4	30 22 40	78 16 36.33	1928	Limestone/NW/45	NNE/80	SE/75
5	30 22 38.66	78 16 41.42	1868	Transition zone of Limestone and quartzite in contact slate with interbedded slate	-	-
6	30 23 03.63	78 16 38.38	2026	Limestone/NW/45	NNE/80	S/75
7	30 24 08.95	78 17 28.13	2234	Weathered Limestone/SSE/40	WNW/80	E/70
8	30 23 28.95	78 17 40.47	1887	Quartzite/SE/65	SW/70	NE/50
9	30 23 4.66	78 17 40.33	1908	Quartzite/SE/65		-
10	30 22 53.66	78 17 41.53	1778	Quartzite/E/55	SW/70	-
11	30 22 57.90	78 17 36.35	1790	Quartzite/E/65	SW/70	NE/50
12	30 22 39.35	78 17 16.41	1720	Quartzite/NE/50	SW/70	SE/50
13	30 23 18.18	78 16 57.32	1822	Limestone with interbedded slate /NW/40	WNW/80	SSE/75
14	30 22 46.46	78 16 51.74	1784	Slate in transition zone	-	-
15	30 24 13.12	78 17 23.61	2316	Weathered zone with slate bands interbedded with limestone	-	-

Influence of rock type on groundwater:

The area is characterized by meta - sedimentary rocks and shows secondary porosity and permeability due to fracturing, folding and faulting of rocks. Therefore, groundwater movement occurs mainly along the secondary porosity and permeability present in these rocks. The springs observed in this region were mostly depression and fracture springs associated with old landslide deposits and fracture zones (Valdiya and Bartarya, 1991). The fractures and joints serve as the conduit for subsurface water.

Geology of the Kotigad watershed

Kotigad Watershed lies in the Tehri Garhwal district. This area is represented by the rocks of Lesser Himalaya and Central Himalaya. The geological set up is very complex due to the repeated tectonic disturbances caused by different orogenic cycles.

The Lesser Himalaya occupies major part of the Tehri district and comprises of different groups like Jaunsar Group, Blaini-Krol Group and Tal Group. In Kotigad watershed, rocks of Phyllite, Slate, Quartzites are common with meta sedimentary shales at some places belonging to the Blaini Group. The groups are subdivided into various formations like Bhilangana Formation, Rautgara Formation, Bijni Formation. Generally, the rocks of the Lesser Himalayan Zone show signs of multiple phases of deformation and metamorphism.

STRUCTURE: Kotigad watershed has highly folded anticlinal mountains with 3 set of fractures in NE, SE, NW directions. However, two sets are more prominent sets of fractures dipping in the North-East and South-East directions with their amounts ranging from 10^0-50^0 but most commonly the beds dip in the North-Eastern direction.

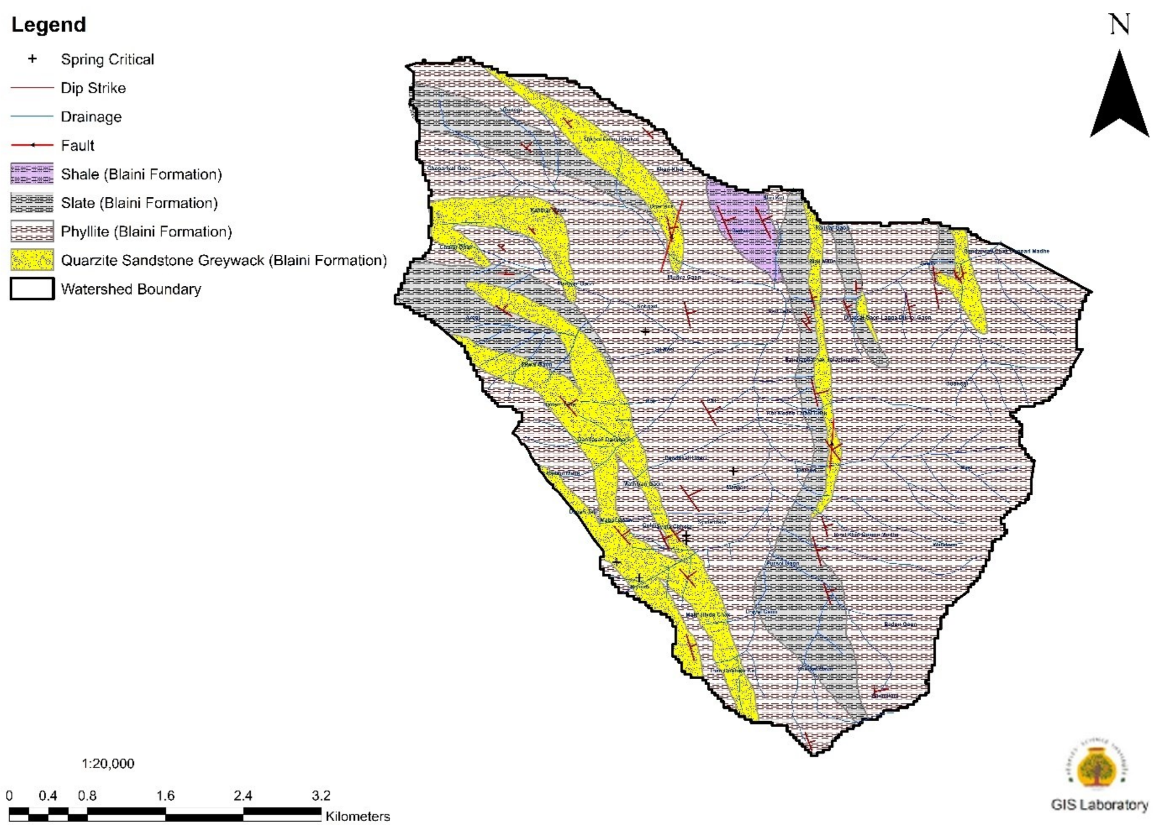


Figure 4. Geological map of Kotigad Watershed

Table 4: Attitude of fracture data in the watershed of Kotigad catchment

	Location		Bedding plane		Fracture				Rock type
	Latitude	Longitude	Dip direction	Amount	F1	F2	F3		
1	30º22'51.36"	78º24'56.60"	60º	41º	48º,N180º	66º,N100º	20º,N280º	1301	Phyllite
2	30º22'47.38"	78º24'48.63"	70º	40º	61º,N100º	82º,N175º	40º,N280º	1285	Phyllite
3	30º22'45.79"	78º24'33.03"	-	-	-	-	-	1292	Phyllite,Quartzite
4	30º22'47.62"	78º24'30.69"	50º	55º	Along bed	45º,N185º	80º,N230º	1290	Slate
5	30º22'49.66"	78º24'26.83"	-	-	-	-	-	1300	Phyllite
6	30º22'42.10"	78º24'15.02"	50º	25º	Along bed	64º,N150º	-	1307	Slate
7	30º22'59.16"	78º25'4.58"	75º	51º	Along bed	60º,N260º	55º,N340º	1137	Slate,Quartzite
8	30º22'58.97"	78º25'7.07"	60º	25º	Along bed	86º,N260º	73º,N310º	1152	Greywacke
9	30º22'57.30"	78º25'05.96"	50º	40º	-	-	-	1165	Slate,Quartzite
10	30º22'58.77"	78º24'57.73"	70º	50º	Along bed	60º,N260º	55º,N340º	1175	Slate,Quartzite
11	30º22'54.03"	78º24'31.86"	80º	60º	Along bed	-	86º,N350º	1221	Slate
12	30º22'50.94"	78º24'17.14"	80º	35º	-	N250º	N340º	1257	Slate,Quartzite
13	30º22'44.12"	78º24'15.70"	60º	25º	-	-	-	1292	Slate,Quartzite
14	30º22'19.10"	78º24'18.53"	80º	27º	70º,N160º	50º,N240º	-	1316	Slate,Quartzite
15	30º22'00.30"	78º24'23.86"	50º	15º	Along bed	-	N330º	1364	Slate,Quartzite
16	30º21'10.55"	78º24'00.10"	-	-	-	-	-	1381	Slate
17	30º21'34.93"	78º24'21.50	70º	20º	50º,N180º	30º,N240º	-	1463	Phyllite
18	30º21'26.62"	78º24'18.82"	70º	20º	º,Nº	º,Nº	-	1441	Slaty Phyllite
19	30º21'12.62"	78º24'22.07"	75º	35º	80º,N140º	78º,N220º	-	1462	Slate
20	30º20'52.67"	78º21'8.99"	-	-	-	-	-	1472	Slate
21	30º20'52.67"	78º23'43.82"	-	-	-	-	-	1500	Sandy Phyllite, Quartzite(low grade)
22	30º20'29.77"	78º23'42.02"	90º	30º	-	-	-	1530	Quartzite
23	30º20'34.63"	78º23'38.39"	-	-	-	-	-	1535	Phyllite
24	30º21'08.57"	78º23'41.85"	-	-	-	-	-	1563	Quartzite
25	30º21'17.28"	78º23'35.62"	40º	40º	-	-	-	1530	Quartzite
26	30º23'16.81"	78º24'00.86	70º	40º	-	-	-	1347	Shale, Phyllite
27	30º23'16.09"	78º23'47.90"	65º	15º	83º,N120º	77º,N210º	60º,N340º	1342	Purple Shale(meta-sedimentary)
28	30º23'13.91"	78º23'29.39"	80º	-	Along bed	-	-	1320	Phyllite, Quartzite
29	30º22'45.44"	78º23'35.32"	80º	30º	70º,N180º	82º,N250º	20º,N330º	1290	Phyllite
30	30º22'22.53"	78º23'46.91"	-	-	-	-	-	1359	Phyllite
31	30º22'12.53"	78º23'42.76"	55º	17º	-	-	-	1383	Phyllite
32	30º21'53.18"	78º23'50.78"	230º	-	-	-	-	1329	Phyllite
33	30º22'40.93"	78º23'22.28"	260º	10º	35º,N40º	60º,N140º	Along bed	1366	Phyllite
34	30º21'20.20"	78º26'00.24"	80º	15º	Along bed	78º,N180º	-	1870	Phyllite
35	30º21'18.85"	78º26'2.53"	75º	40º	Along bed	77º,N140º	53º,N235º	1879	Quartzite
36	30° 21' 17.6508"	78° 26' 14.8842"	-	-	-	-	-	1862	Phyllite, Quartzite

37	30º21'4.80	78º26'33.62"	75º	23º	Along bed	-	-	1844	Slate, Quartzite
38	30º21'00.42"	78º26'36.62"	75º	17º	-	-	-	1808	Phyllite, Quartzite
39	30º20'57.99"	78º26'39.59"	70º	10º	Along bed	70º,N140º	50º,N270º	1821	Phyllite, Quartzite, Slate
40	30º20'55.49"	78º26'55.23"	-	-	-	-	-	1776	Phyllite
41	30º21'3.13"	78º26'58.61"	80º	34º	Along bed	75º,N220º	82º,N290º	1684	Slaty Phyllite
42	30º21'21.15"	78º27'23.89"	80º	30º	Along bed	30º,N145º	º,Nº	1328	Quartzite
43	30º21'27.52"	78º26'39.68"	90º	57º	Along bed	40º,N170º	38º,N250º	1612	Phyllite, Quartzite
44	30º21'28.23"	78º26'31.41"	70º	55º	-	-	-	1619	Phyllite
45	30º21'31.11"	78º26'16.73"	70º	-	-	-	-	1645	Quartzite
46	30º22'00.85"	78º25'41.08"	40º	50º	60º,N130º	45º,N240º	85º,N340º	1840	Slate, Quartzite
47	30º21'58.31"	78º25'53.40"	70º	35º	Along bed	45º,N150º	15º,N185º	1834	Phyllite
48	30º21'44.48"	78º25'40.27"	70º	40º	-	62º,N250º	86º,N330º	1867	Slaty Phyllite, Quartzite
49	30º21'22.48"	78º25'40.53"	50º	55º	Along bed	64º,N145º	55º,N345º	1909	Phyllite
50	30° 21' 23.3748"	78° 25' 29.0094"	-	-	-	-	-	1921	Phyllite
51	30° 21' 23.3841"	78° 25' 10.0094"	-	-	-	-	-	1880	Phyllite
52	30º20'39.66"	78º24'38.10"	80º	45º	-	-	-	1801	Phyllite
53	30º20'29.34"	78º24'39.45"	40º	26º	75º,N80º	76º,N140º	Along bed	1769	Slaty Phyllite
54	30º20'27.48"	78º24'44.89"	75º	25º	Along bed	72º,N260º	82º,N330º	1742	Phyllite
55	30º20'25.63"	78º24'58.88"	60º	30º	Along bed	65º,N140º	78º,N250º	1659	Phyllite
56	30º20'25.85"	78º25'8.06"	80º	50º	Along bed	45º,N160º	20º,N350º	1626	Slaty Phyllite
57	30º20'25.00"	78º25'8.67"	85º	50º	Along bed	45º,N250º	60º,N345º	1659	Phyllite, Slate, Quartzite
58	30º20'23.11"	78º24'16.06"	80º	35º	-	-	-	1752	Phyllite
59	30º20'35.73"	78º23'47.06"	-	-	-	-	-	1639	Phyllite
60	30º21'45.20"	78º23'36.11"	50º	10º	-	-	-	1426	Phyllite
61	30º21'32.42"	78º23'31.93"	40º	10º	Along bed	65º,N110º	50º,N220º	1449	Phyllite, Quartzite
62	30º21'30.82"	78º23'27.71"	45º	10º	Along bed	70º,N125º	62º,N220º	1459	Phyllite, Quartzite
63	30º23'45.46"	78º23'22.84"	40º	10º	Along bed	65º,N150º	71º,N340º	1744	Phyllite
64	30º23''49.14"	78º22'55.92"	50º	15º	Along bed	75º,N130º	52º,N240º	1774	Quartzite
65	30º23'40.65"	78º22'42.21"	38º	10º	56º,N60º	72º,N140º	-	1807	Slate
66	30º23'26.57"	78º22'36.64"	310º	42º	78º,N150º	54º,N230º	Along bed	1757	Phyllite
67	30º23'23.71"	78º22'45.25"	310º	22º	89º,N100º	86º,N220º	-	1756	Slate, Quartzite
68	30º23'19.57"	78º22'51.55"	30º	10º	85º,N10º	60º,N110º	80º,N340º	1752	Quartzite
69	30º23'14.08"	78º22'56.20"	-	-	-	-	-	1736	Phyllite
70	30º23'13.40"	78º22'43.94"	45º	20º	Along bed	64º,N120º	65º,N210º	1760	Quartzite
71	30º23'7.71"	78º22'33.97"	30º	55º	Along bed	66º,N125º	56º,N230º	1788	Phyllite
72	30º22'58.33"	78º22'35.38"	10º	25º	Along bed	75º,N120º	-	1803	Slate
73	30º22'46.05"	78º22'34.66"	30º	20º	Along bed	75º,N140º	55º,N310º	1776	Phyllite, Slate, Quartzite
74	30º22'15.03"	78º22'55.83"	50º	28º	30º,N140º	46º,N210º	84º,N330º	1738	Quartzite
75	30º23'43.40"	78º21'56.53"	-	-	-	-	-	2127	Phyllite

76	30º23'40.43"	78º21'58.58"	30º	25º	Along bed	-	-	2121	Phyllite
77	30º23'16.17"	78º22'1.01"	10º	25º	Along bed	80º,N220º	89º,N330º	2055	Quartzite
78	30º23'8.00"	78º21'57.04"	50º	20º	-	-	-	2047	Phyllite
79	30º23'1.29"	78º21'58.54"	10º	30º	Along bed	50º,N240º	-	2017	Slaty Phyllite
80	30° 22' 46.7934"	78° 21' 54.0648"	10º	24º	-	-	-	1998	Phyllite
81	30º22'44.32"	78º22'4.51"	10º	20º	-	-	-	1973	Phyllite
82	30º22'44.38"	78º22'4.54"	20º	32º	-	78º,N260º	65º,N330º	1978	Slate
83	30º22'38.81"	78º22'14.32"	0º	20º	-	-	-	1963	Slate, Quartzite
84	30º22'33.66"	78º22'17.55"	20º	32º	Along bed	78º,N210º	N340º	1936	Quartzite, Phyllite
85	30º22'25.51"	78º22'23.62"	-	-	-	-	-	1913	Slate, Phyllite, Quartzite
86	30º22'3.89"	78º22'6.21"	30º	31º	Along bed	60º,N220º	45º,N310º	1858	Quartzite
87	30º22'2.03"	78º22'30.55"	-	-	-	-	-	1823	Phyllite
88	30º21'53.91"	78º22'48.02"	240º	30º	-	-	-	1795	Slate, Phyllite
89	30º21'49.68"	78º22'58.86"	230º	20º	55º,N30º	-	65º,N320º	1774	Phyllite
90	30° 21' 43.4592"	78° 23' 10.6188"	-	-	-	-	-	1726	Quartzite
91	30° 21' 35.1426"	78° 23' 16.9362"	-	-	-	-	-	1702	Phyllite
92	30º21'32.09"	78º23'14.26"	40º	45º	70º,N140º	30º,N210º	71º,N320º	1718	Quarztite
93	30º20'57.93"	78º23'43.65"	-	-	-	-	-	1565	Quartzite
94	30º20'57.06"	78º23'39.20"	-	-	-	-	-	1569	Phyllite
95	30º20'54.69"	78º23'36.48"	50º	-	-	-	-	1576	Quarztite
96	30º20'48.15"	78º23'25.12"	40º	35º	Along bed	60º,N180º	55º,N270º	1551	Phyllite
97	30º20'13.40"	78º22'58.81"	70º	10º	-	75º,N240º	70º,N320º	1477	Phyllite
98	30º20'19.12"	78º23'6.35"	180º	50º	51º,N120º	-	55º,N340º	1483	Phyllite
99	30º20'33.70"	78º22'59.24"	-	-	-	-	-	1507	Quartzite, Phyllite
100	30º20'39.32"	78º23'3.01"	130º	-	-	-	-	1509	Phyllite

Hydrogeology of the watershed:

The metamorphics are generally characterized by secondary porosity and permeability due to weathering and fracturing of rocks. Therefore, groundwater movement occurs mainly along the secondary porosity and permeability and through weathered zones present in these rocks. The springs observed in this region were mostly depression springs and fracture springs associated with old landslide deposits and weathered zones and fracture zone (K.S. Valdiya, S.K. Bartarya; 1991). The fractures and joints serve as the conduit for subsurface water.

Geology of the Malan Watershed

Malan Watershed lies in the Pauri Garhwal district. The rocks of the watershed belong to the Lesser Himalayan Zone and is characterized by superimposed thrust sheets mainly North Almora Thrust (NAT) in the north-eastern part. The thrust is traversed by two faults trending NE-SW and NNE-SSW namely Burkot and Koteshwar faults. The geological set up is very complex due to the repeated tectonic disturbances caused by different orogenic cycles.

The geological map shows that the rocks are dipping in North-East and South-West directions with their amounts ranging from 20^0-60^0 but most commonly the beds dip in the South-West direction therefore having a strike in NW-SE direction. Rocks commonly present are Quartzites, Phyllites, Slates, Schists of Nathuwakhan Formation belonging to Ramgarh group are common with Mica schistat at few some places.

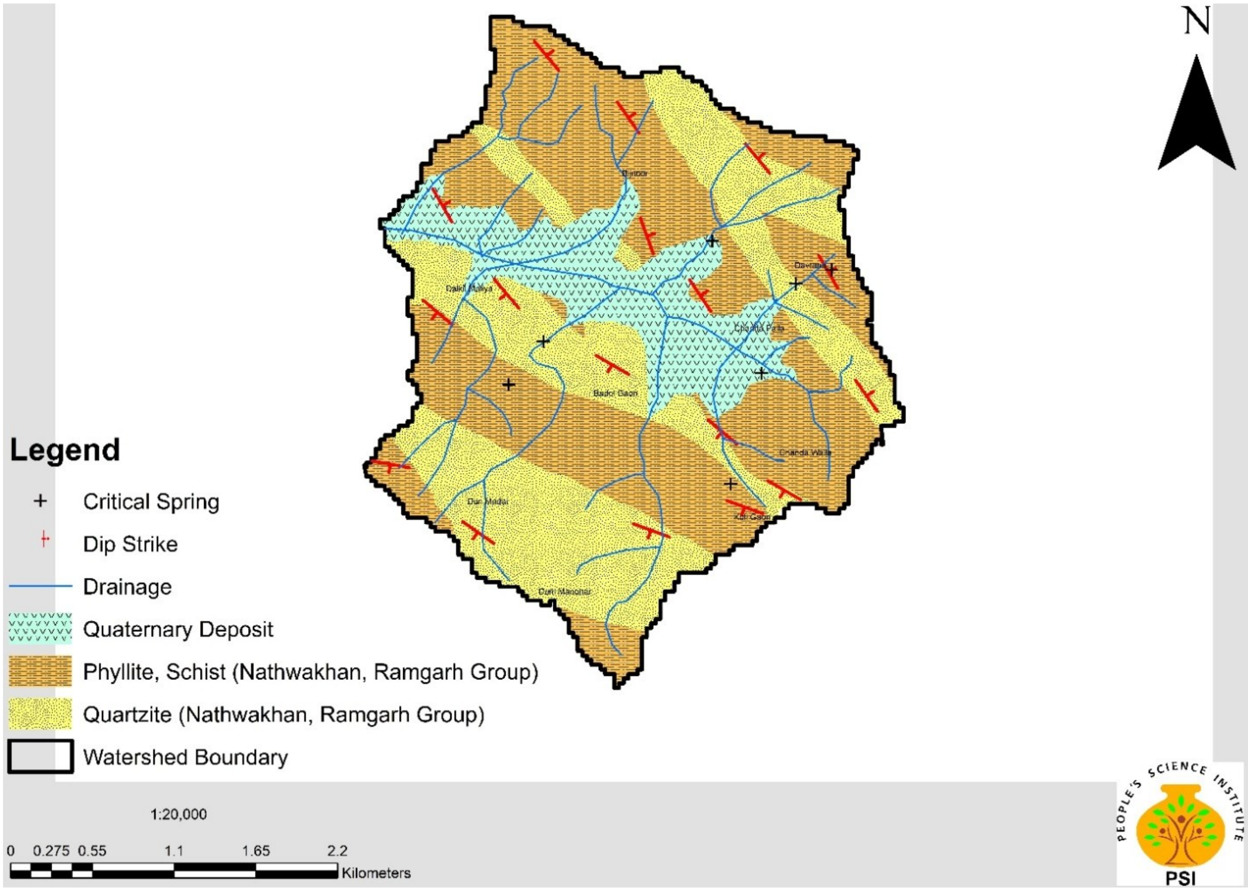


Figure 5. Geological map of the Malan watershed

Structure:

Malan watershed has highly folded anticlinal mountains with 4 set of fractures in NE, SE, NW and SW directions (Table 1). Rocks of Phyllite, Slate, Quartzites

Hydrogeology of the area:

The rocks present in the watershed are generally characterized by secondary porosity and permeability due to weathering and fracturing of rocks. Therefore, groundwater movement occurs mainly due to secondary porosity and permeability present in these rocks.The springs observed in this region were mostly depression springs and fracture springs associated with old landslide deposits and weathered zones (Valdiya and Bartarya, 1991).The fractures and joints serve as the conduit for subsurface water.

Table 5: Fracture and Joints data in the Malan watershed

S.No	Location		Elevation (m)	Rock Type	Bedding Plane		Fracture							
	Latitude	Longitude			Dip direction (N)	Amount	F1(1-90)	Amount	F2 (91-180)	Amount	F3 (181-270)	Amount	F4(271-360)	Amount
1	29.858296	78.5460716	982	unconsolidated quartzite	-	-	-	-	-	-	-	-	-	-
2	29.856225	78.548498	996	quartzite	240	40	70	68					345	50
3	29.865926	78.549675	995	unconsolidated phyllite	-	-	-	-	-	-	-	-	-	-
4	29.855668	78.553568	1022	unconsolidated quartzite	-	-	-	-	-	-	-	-	-	-
5	29.853365	78.557658	1045	unconsolidated quartzite	-	-	-	-	-	-	-	-	-	-
6	29.84276	78.56375	1264	unconsolidated	-	-	-	-	-	-	-	-	-	-
7	29.845701	78.563318	1196	highly weathered phyllite	250	30	-	-	-	-	-	-	-	-
8	29.851165	78.562186	1076	quaternary deposit	-	-	-	-	-	-	-	-	-	-
9	29.844655	78.56251	1201	unconsolidated-mostly gneiss,phyllite and quartzite	-	-	-	-	-	-	-	-	-	-
10	29.84884	78.56051	1140	quartzite and phyllite	230	50	40	62	-	-	230	50	310	61
11	29.84781	78.560583	1137	quartzite with quartzite veins	220	55	45	60	-	-	220	55	310	60
12	29.84772	78.56123	1091	highly weathered phyllite	220	30	-	-	-	-	-	-	-	-
13	29.85013	78.5609	1095	unconsolidated phyllite	-	-	-	-	-	-	-	-	-	-
14	29.85489	78.56029	1074	quartzite, phyllite	45	20	-	-	165	62	245	58	-	-
15	29.85515	78.55998	1076	weathered quartzite	30	15	-	-	-	-	-	-	-	-
16	29.85541	78.56014	1070	phyllite with quartz veins	46	20	-	-	-	-	-	-	-	-
17	29.85701	78.55599	1072	quartzite and phyllite	55	22	55	22			190	61	285	65
18	29.85753	78.55397	1040	phyllite	60	20	60	20	180	71	270	78		
19	29.85823	78.55168	1032	unconsolidated-phyllite,gneiss,quartzite	-	-	-	-	-	-	-	-	-	-
20	29.8591	78.54982	993	unconsolidated-gneiss,quartzite	-	-	-	-	-	-	-	-	-	-
21	29.86036	78.54642	977	unconsolidated-phyllite,schist	-	-	-	-	-	-	-	-	-	-
22	29.86043	78.544993	980	schist,phyllite	50	25	50	25	170	68	260	71	-	-
23	29.87002	78.551033	1464	phyllite	30	10	30	10	140	67	220	67	-	-
24	29.86949	78.551263	1445	schist	35	47	35	47	160	72	250	70	-	-
25	29.87002	78.55058	1460	unconsolidated-schist	-	-	-	-	-	-	-	-	-	-
26	29.86936	78.55218	1493	phyllite	40	35	-	-	-	-	-	-	-	-
27	29.8706	78.55186	1496	phyllite,schist	30	35	-	-	-	-	-	-	310	55
28	29.84083	78.564415	1360	phyllite	200	70	-	-	100	62	-	-	290	51
29	29.84146	78.56528	1354	quartzite	200	85	-	-	100	61	200	85	290	51
30	29.84204	78.565321	1364	quartzite,phyllite	210	65	-	-	115	63	210	65	295	49
31	29.84346	78.565706	1354	phyllite,quartzite	190	70	-	-	98	70	190	70	280	53
32	29.865452	78.552461	1350	weathered schist	45	30	45	30	170	68	260	70	-	-
33	29.86583	78.55632	1460	weathered phyllite	55	28	-	-	-	-	-	-	-	-
34	29.86383	78.56393	1602	quartzite,phyllite	50	30	50	30	-	-	190	62	280	62
35	29.85074	78.56571	1215	weathered phyllite	-	-	-	-	-	-	-	-	-	-
36	29.85635	78.56837	1313	phyllite	50	40	50	40	175	68	260	70	-	-

37	29.84944	78.57038	1335	quartzite	55	48	55	48	165	62	245	58	-	-
38	29.84058	78.55755	1501	quartzite	200	68	-	-	100	61	200	68	300	53
39	29.84021	78.54659	1656	quartzite	215	65	-	-	115	63	215	65	310	61
40	29.84481	78.54195	1571	phyllite	190	63	-	-	120	65	190	63		
41	29.85526	78.54545	1080	quartzite	205	60	-	-	110	60	205	60	320	61

Geology of the Moldhar watershed

Moldhar watershed lies in the Jaunpur block of Tehri Garhwal district in Uttrakhand. The area is represented by the rocks of Lesser Himalaya. The geological set up is very complex due to the repeated tectonic disturbances caused by different orogenic cycles.

Jaunsar Group (Lower Palaeozoic to Proterozoic)	**Nagthat – Berinag Formation** **Chandpur Formation** Mandhali Formation	**Quartzites interbedded with slates and phyllites** **Slates and Phyllite** Carbonaceous phyllite, slate, and minor limestone
Tejam Group (Proterozoic)	Deoban Formation	White and light pink dolomites
Damtha Group (Proterozoic)	Rautgara Formation	Quartzites interbedded with sublitharenites, slates and metavolcanics.

Regional Geology of the Area (after Valdiya,1980)

All the three formations of Jaunsar i.e., Mandhali, Chandpur and Nagthat are located to the east of Chakrata in Yamuna valley. Mandhali limestone is partly equivalent to Deoban (Tejam). Chandpur slates and phyllites sometimes with bands of quartzites are exposed in Aglar valley in Tehri, around Deoprayag in Ganga and Pauri-Ghurdauri Road section in Garhwal and also in the lower reaches of Machhlad and Purvi Nayar. These phyllites are overlain by thick Nagthat quartzites which are best exposed in Nagthat hill on the right bank of Yamuna River. These quartzites are very extensive throughout the Lesser Himalaya in a linear belt below the Krol Group of rocks.

A drainage is observed at the middle of the watershed with alluvial fan deposits in it. This drainage separates the rock type of the two formations. To the North of the drainage lies the rocks of Chandpur Formation consisting of Slates, Phyllites and meta-Siltstone whereas to the South lies the rocks belonging to the Nagthat Formation comprising Quartzites.

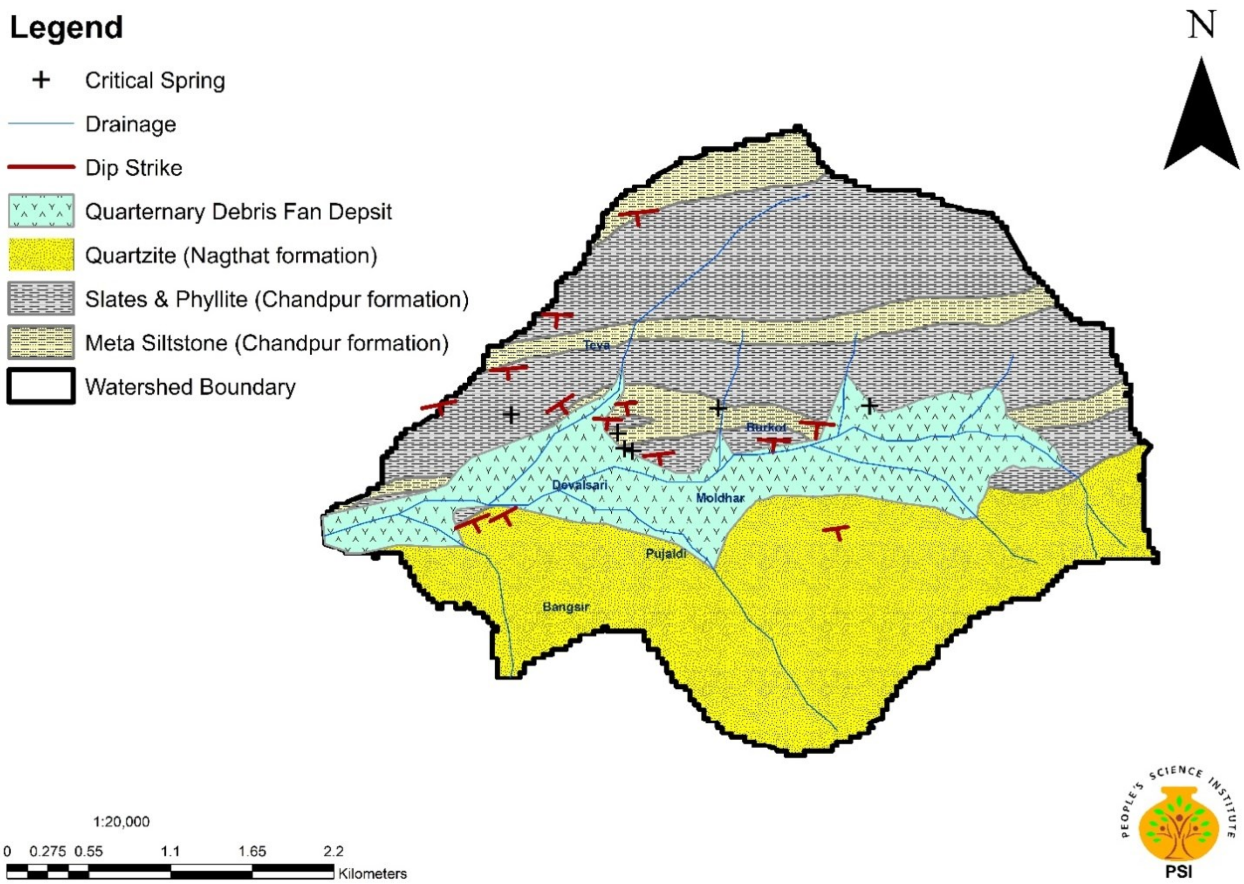


Figure 6: Geological map of the Moldhar watershed

Fracture Data of the Moldhar Watershed

Moldhar watershed has highly folded anticlinal structure with 3-set of fractures in NW, SE and NE directions. Rocks present are phyllites, slates and quartzites. The rocks are mainly dipping in SE direction with its amount ranging from 15 - 45o but most commonly the beds dip in the NE direction and so therefore its strike is in NE-SW direction.

Hydrogeology of the Moldhar Watershed

The Phyllites and Quartzites are characterized by secondary porosity and permeability due to weathering and fracturing of rocks. Therefore, groundwater movement occurs mainly due to secondary porosity and permeability present in these rocks.The springs observed in this region were mostly depression springs and fracture springs associated with old landslide deposits and fractured and weathered zones (Valdiya and Bartarya, 1991). The fractures and joints serve as the conduit for subsurface water.

Table 6: Attitude of fracture data in the watershed of Moldhar catchment

S.No	Location		Bedding Plane		Fracture			Rock Type
	Latitude	Longitude	Dip direction	Amount	F1	F2	F3	
1	30º32'40.83"	78º12'2.80"	-	-	-	-	-	Quartzite boulders
2	30º32'29.10"	78º11'55.89"	-	-	-	-	-	Quartzite boulders
3	30º32'33.28"	78º12'04.01"	-	-	-	-	-	Quartzite boulders
4	30º32'39.10"	78º12'17.15"	-	-	-	-	-	Quartzite boulders
5	30º32'33.08"	78º12'25.74"	N160º	15º	85º,N60º	Along bed	70º,N355º	Quartzite
6	30º32'55.20"	78º12'26.31"	-	-	-	-	-	Quartzite boulders
7	30º32'52.23"	78º12'26.00"	-	-	-	-	-	Flood plain deposits
8	30º32'56.61"	78º12'22.40"	-	-	-	-	-	unconsolidated, Phyllite
9	30º32'56.07"	78º12'20.81"	N190º	15º	-	-	-	unconsolidated: meta sedimentary Shale,Phyllite
10	30º32'52.69"	78º12'11.60"	N180º	20º	-	-	-	unconsolidated, Phyllite
11	30º32'56.76"	78º11'35.90"	N180º	10º	55º,N80º	Along bed	51º,N340º	Phyllite, Quartzite
12	30º33'00.14"	78º11'25.24"	N150º	15º	78º,N70º	Along bed	54º,N340º	Phyllite
13	30º31'55.11"	78º11'20.01"	-	-	-	-	-	unconsolidated, Phyllite
14	30º32'43.51"	78º11'20.19"	-	-	-	-	-	Flood plain deposits
15	30º32'46.85"	78º10'58.19"	-	-	-	-	-	unconsolidated, Phyllite
16	30º32'54.75"	78º10'44.11"	N160º	25º	51º,N30º	-	68º,N310º	Phyllite, Quartzite
17	30º32'49.04"	78º11'46.67"	N160º	38º	Along bed	70º,N210º	68º,N330º	Phyllite
18	30º32'50.10"	78º11'30.31"	-	-	-	-	-	Quartzite boulders
19	30º32'40.87"	78º11'22.29"	-	-	-	-	-	Quartzite boulders
20	30º32'35.39"	78º11'12.93"	N150º	45º	80º,N60º	Along bed	84º,N340º	Quartzite
21	30º32'33.45"	78º11'6.93"	N160º	15º	78º,N60º	Along bed	71º,N320º	Quartzite
22	30º32'59.52"	78º11'38.81"	N175º	20º	65º,N80º	Along bed	68º,N345º	Quartzite
23	30º33'0.20"	78º10'59.28"	N160º	45º	25º,N60º	-	65º,N345º	Phyllite
24	30º33'07.48"	78º10'58.28"	N170º	50º	60º,N80º	48º,N325º	25º,N30º	Quartzite
25	30º33'50.58"	78º11'16.30"	-	-	-	-	-	unconsolidated debris
26	30º33'49.35"	78º11'17.29"	-	-	-	-	-	unconsolidated debris
27	30º33'50.94"	78º11'16.52"	N170º	30º	78º,N65º	Along bed	50º,N330º	Quartzite
28	30º33'50.19"	78º11'13.10"	-	-	-	-	-	Phyllite, Quartzite
29	30º33'14.03"	78º10'38.98"	-	-	-	-	-	Flood plain deposits
30	30º33'19.22"	78º10'38.50"	N180º	15º	-	-	-	Phyllite
31	30º33'22.58"	78º10'37.98"	-	-	-	-	-	Quartzite boulders

Interpretation of Soil Porosity & Infiltration

Six watersheds in two districts (Tehri Garhwal and Pauri Garhwal) of Uttarakhand were selected for study of 120 springs. The idea was to demarcate the potential recharge area of these springs and actually implement measures to increase the discharge of 30 selected critical springs in these watersheds (approx. five springs per watershed).

The soil samples from about 100 locations from each watershed, especially from the catchment area of the springs, were collected and analysed for its texture and porosity. Infiltration rate study was also done at all these locations.

Soil samples were also tested for the distribution of sand, silt and clay. Sieve analysis was done at the PSI (collaborator) laboratory. Based on the percentage distribution of sand in the soil samples, soil clusters were marked on the watershed denoting three types of clusters. The area marked in green had less sand percentages ranging from 20-35%, area in blue represents cluster with sand distribution of 35-50% and the area in pink represents cluster with sand distribution of 50-70%. Based on these clusters, the potential recharge area was extended to see if any additional area needs to be treated.

Bareth Watershed

Bareth watershed with an area of 528 ha was the first watershed that was taken up for study. 48 springs were identified in the watershed and nearby areas. Out of these, five springs were selected as critical springs. Since Seem 1 and Seem 2 were adjacent springs with same recharge area, they were considered as one spring. After Amity teams visit, the area was further increased to about 1058ha. As per geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate in the watershed varied from 0.08 to 0.37cm/min. However, in most of the cases it was between 0.10-0.15 cm/min. This indicates that the soil is silty loam to loamy sand with quick recharge potential.

The porosity of the soil varies from 0.36 to 0.41. However, in most cases it is 0.37. The porosity table has been provided with the report. This means that the porosity of the watershed is about 37% which indicates that the soil is mostly clayey sandy gravel to sandy gravel.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50% we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Seem 1 and 2	0.54 ha	unchanged
2	Takaan	39.1 ha	unchanged
3	Samayi	6.0 ha	unchanged
4	Bhiradi 2	6.54 ha	unchanged
5	Sisrana	4.44 ha	unchanged

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that there was no change in recharge area of these springs. All the selected springs were depression springs.

Ghurdauri Watershed

Ghurdauri watershed is close to about 1050ha in area. 18 springs have been identified in the watershed of which five were marked as critical. As per geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate of the watershed varied from 0.1 to 1.6 cm/min. In most of the cases it was, however near to 1cm/min. This indicates that the soil type is mostly sandy to gravelly sand.

Sieve analysis of the samples was done. Based on the proportion of the different soil particle sizes, the porosity of the soils was determined. The porosity table has been provided with the report. The porosity of the watershed varies from 0.34 to 0.36. In most cases it is around 0.36. This means that the porosity of the watershed is about 36% which indicates that the soil is mostly clayey sandy gravel to sandy gravel. This also confirms that the recharge in the area would be fast.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50%, we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Pani Dhara	4.33 ha	2.15ha
2	Pani ku Dhara	1.78 ha	1.38ha
3	Nyanu Dhara	4.52 ha	2.28
4	Panidhara Tok Pankhet	1.11 ha	unchanged
5	Pipal Dhara	1.45 ha	unchanged

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that in two out of five springs there was no change. In the other three, the increase is about 40%.

Kaddukhal Watershed

Kaddukhal watershed has an area of 1037 ha. 20 springs were identified in the watershed. Out of these, five springs were selected as critical springs. Most of the recharge area of these springs fall in reserved forest. As per geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate in the watershed varied from 0.03 to 0.34cm/min. However, in most of the cases it was around 0.2 cm/min. This indicates that the soil is silty loam to loamy with normal recharge potential.

The porosity of the soil varies from 0.35 to 0.39. However, in most cases it is 0.37. The porosity table has been provided with the report. This means that the porosity of the watershed is about 37% which indicates that the soil is mostly clayey loamy sand to loamy sandy gravel.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50% we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Baisakhi Pani	0.75 ha	unchanged
2	Furkani Pani	1.65 ha	unchanged

3	Chorgad	2.81 ha	unchanged
4	Faknaula	1.18 ha	unchanged
5	Silwani	3.43 ha	3.0 ha

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that there was no change in recharge area of four springs. In one spring the area increased by about 85%.

Kotigad Watershed

The Kotigad watershed is about 2440 ha in area. 20 springs were identified in the watershed area out of which six springs were critical. As per geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate of the watershed varied from 0.17 to 0.62 cm/min. In most of the cases it was, however near to 0.3cm/min. This indicates that the soil type is mostly loamy sand to sandy. This also indicates that the recharge rate in these areas would be fast if any recharge measure is taken,

Sieve analysis of the samples was done. Based on the proportion of the different soil particle sizes, the porosity of the soils was determined. The porosity table has been provided with the report. The porosity of the watershed varies from 0.34 to 0.39. In most cases it is between 0.35 and 0.36. This means that the porosity of the watershed is about 35% which indicates that the soil is mostly clayey sandy gravel to sandy gravel. This also confirms that the recharge in the area would be fast.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50% we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Pipal Pani Dhara	3.76 ha	unchanged
2	Katal Dhara	1.1 ha	Unchanged (sand<35%)
3	Silwani Dhara	3.9 ha	Unchanged (sand<35%)
4	Bela Kua	0.92 ha	0.08ha
5	Chamoli Tokh	0.27 ha	unchanged
6	Akhudi Pani	1.25 ha	0.27 ha

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that in four out of six springs, there has been no change in the recharge area. Even in the other two springs, there is a marginal increase in the recharge area.

Malan Watershed

Malan watershed is about 866ha in area. In the watershed, five critical springs were selected out of a total of 19 springs. As per geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate in the watershed varied from 0.07 to 0.27cm/min. However, in most of the cases it was 0.21cm/min. This indicates that the soil is sandy loam to loamy sand with quick recharge potential.

The porosity of the soil varies from 0.38 to 0.39. However, in most cases it is 0.36. The porosity table has been provided with the report. This means that the porosity of the watershed is about 36% which indicates that the soil is mostly clayey sandy gravel to sandy gravel.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50% we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Pungdi Naula	0.8 ha	Unchanged
2	Dalkhil Maliyan	6.4 ha	Unchanged
3	Cupkya Pani Dhara	0.6 ha	Unchanged
4	Naula Badol	0.8 ha	Unchanged
5	Shyera Dhara	1.2 ha	Unchanged

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that there was no change in spring recharge area. All the selected springs were depression type.

Moldhar Watershed

Moldhar watershed is about 1194ha in area. In the watershed, six critical springs were selected out of a total of 20 springs. As per the geological investigations, the potential recharge area of these springs was identified as given in the table. The infiltration rate in the watershed varied from 0.08 to 0.37cm/min. However, in most of the cases it was between 0.11-0.13 cm/min. This indicates that the soil is sandy loam to loamy sand with quick recharge potential.

The porosity of the soil varies from 0.35 to 0.38. However, in most cases it is 0.36. The porosity table has been provided with the report. This means that the porosity of the watershed is about 36% which indicates that the soil is mostly clayey sandy gravel to sandy gravel.

After extending the identified recharge areas of these springs on the basis of soil clusters where sand exceeds 50% we find the following observations as given in the table:

SNo.	Critical Springs	Area Identified through hydro-geological study	Extended area through porosity study
1	Sena Dhara	1.82 ha	0.4 ha
2	Sema Tok 1	2.19 ha	Unchanged
3	Dhara Pani	2.0 ha	0.31 ha
4	Kanthi Bagi	2.82 ha	Unchanged
5	Getu ka Paniyar	0.78 ha	0.22 ha
6	Upala Shivani Dhara	4.1 ha	Unchanged

On the basis of sand cluster, the potential recharge area was extended for all the springs. It is observed that there was no change in recharge area of three springs. However, there was about 15-20 increase in the recharge area of the other three springs.

Based on the analyses, the following inferences were arrived at:

- The soils in all the watersheds have medium porosity which indicates that the water absorbance capacity is high but the retaining capacity is low. The recharge activities will provide immediate results in the discharge of these springs.
- The geo-hydrology study to demarcate the recharge area remains unchanged in most of the springs after extension of the recharge area on the basis of sand clusters.

- The increase of discharge with implementation on the identified recharge area has shown encouraging results. The study of soil infiltration rate and porosity was not that important as far as recharge area delineation is concerned.
- There have been some limitations to the study especially the infiltration rate study which requires at least 1.5 to 2 hours in the field per site for testing and ample amount of water. Also, the depth of existing soil had created further hindrances in the study.

Direct Injection of Rainwater to Aquifers

A novel technique has been developed using defunct or unused handpumps to recharge the aquifer directly connected to them with about 80-90% of the rain water received through rooftop or collected through surface runoff. This technique is very usefully for mountainous region.

Deep bore India Mark-II handpump has been successfully installed in Uttarakhand mountain region since 1998. Due to various reasons, about 2000 in the hilly areas & 1517 in the plains, a total of 3517 hand pumps have been reported to be non-working/inoperative. The major reasons for becoming defunct is due to depletion/drying up of underground connected aquifers to the concerned handpumps.

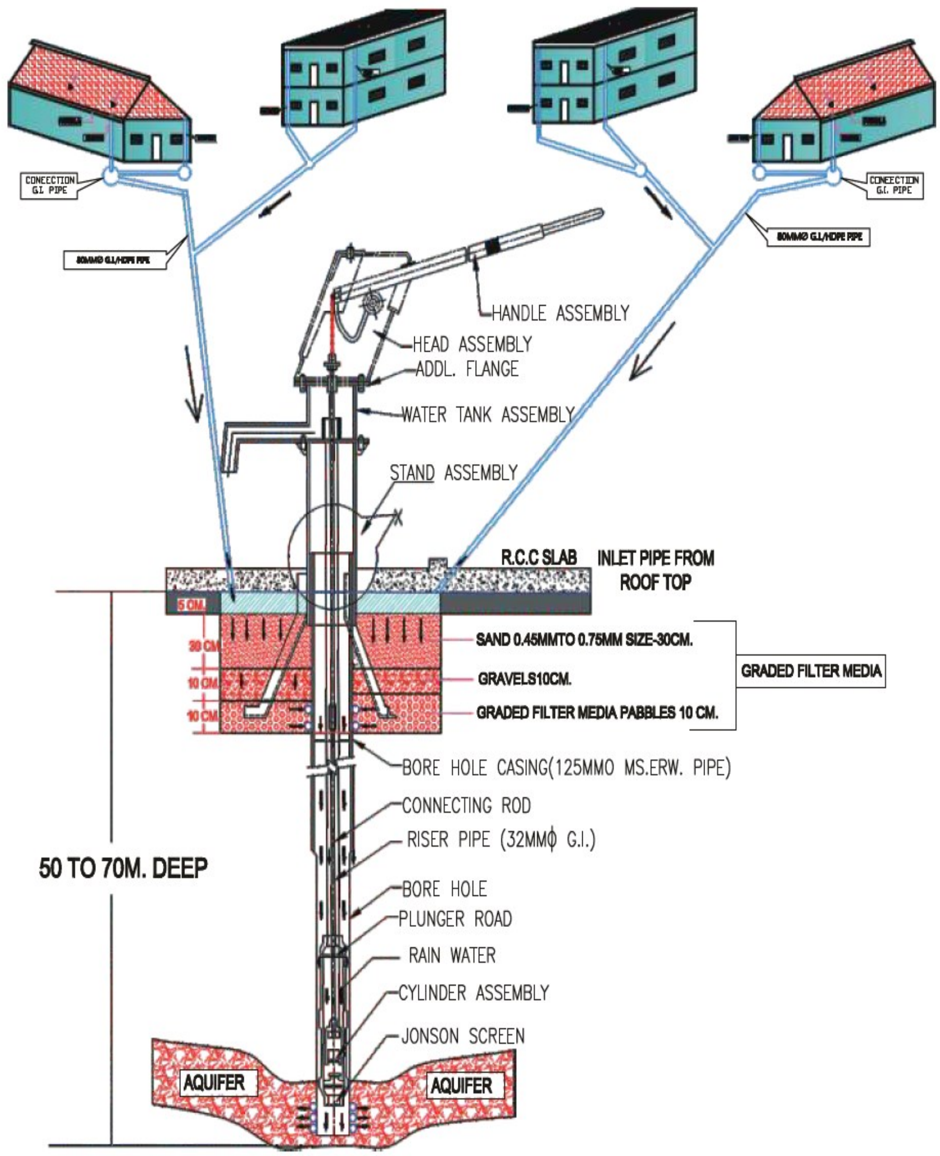
These hand pumps have been working smoothly for the last 15-20 years, because the availability of water sources was good enough to pump water through these handpumps. These hand pumps were connected to underground aquifer and where the aquifer has depleted or dried up and not getting sufficient water for pumping through handpumps such handpumps has become defunct or non-operative. To revive these hand pumps, the aquifer/water sources located at a depth of 50-80m below have to be recharged, so that the hand pumps can become functional again. To revive defunct handpumps new technology has been developed.

Details of Innovative Technology

The purpose of this innovative technique is that the rain falling on the roof of houses or buildings is collected through drainage pipe (down pipe) and carried through a distribution network of HDPE pipe and pass through graded filter media before it enters the underground water source. After treatment, treated water enter the casing pipe of the handpump and directly reaches to the underground aquifer. Graded filter media, which is developed by excavating the surface of the hand pumps to a depth of one meter, filled with a layer of sand, charcoal and stone gravel as filter media, is used for purification of water. At the bottom of the filter, the casing pipe of 5 inch diameter is made perforated with 24 holes of 0.5 mm diameter all around the pipe surface, so that after purification, the purified water can go inside the casing pipe of the hand pump, with the help of the inner surface of the casing pipe can directly reaches to the aquifer. The handpump consist of two G.I. pipes, outer GI pipe of 125mm (5 inch) diameter is called casing pipe which supports the outer surface of the bore, and the inner G.I. pipe of 32mm dia is called the pump assembly pipe of the handpump. In this way, there is a gap of about 93mm between the two pipes, through which the rainwater easily reaches the aquifer, and it does not affect the functioning of pumping assembly of the hand pump. Therefore, the hand pump can function as before.

By this method, up to 70-80 percent of the rain falling on the roof of the buildings could be collected through drainage pipe and sent to the filter unit with the help of distribution system. After purification, this purified water reaches directly to the aquifer/water source located at a depth of 50-80 m with the help of the inner surface of the casing pipe through 24 holes made at the bottom of the casing pipe. All this process is completed within 5-10 minutes and in this whole process there is no possibility of water losses due to evaporation, soil moisture etc. Therefore, the entire 80-90 percent water collected directly reaches the underground aquifer/water source in minimum time. This complete process is described in the related figures 1-2 as follows-

Figure shows the details of hand pump with surrounding filter assembly connected with piping network for collecting rain water from roof top in the system, for direct injection of harvested rainwater to aquifer after filtering.



SECTIONAL DETAILS OF INDIA MARK-III (VLOM) DEEPWELL HAND PUMP SYSTEM ASSEMBLY

The cost of this whole process works out to be Rs. 80000- 1 Lac per site and if the connected rooftop area is 400-500 sqm then it can recharge the ground water aquifer with approximately 4-5 Lakh litre of water annually. This water not only revives the defunct handpumps but will also recharge the downstream springs sources connected to this aquifer. This process is 4-5 time cheaper than conventional methods of recharging the water source.

Resourcesat - LISS-III satellite imagery with a spatial resolution of 23.5 m with three visible bands and one infrared band, dated October 2016 of Pauri region was acquired from the official ISRO's Geoportal, Bhuvan (https://bhuvan-app3.nrsc.gov.in/data/download/index.php). ALOS-Palsar digital elevation model with a spatial resolution of 12.5 meters for the entire study area catchment was downloaded from Earthdata, NASA's data hub (https://search.asf.alaska.edu/#/?dataset=ALOS).

Groundwater, in Tehri and Pauri Garhwal district, generally occurs locally within disconnected bodies under favourable geohydrological conditions such as in channel and alluvial terraces of river valleys, joints, fractures and fissures of crystalline and metasedimentary rocks, well vegetated and relatively plain areas of valley portions and in subterranean caverns of limestone and dolomitic limestone country rocks. The occurrence and movement of ground water depend not only on the nature of the litho units and the nature of the interspaces/ interstices but also on the degree of interconnection between them, the vertical and aerial extension of joints, faults and/or shear zones and the local and regional geomorphology. Gadheras are the group of springs coming from higher reaches of the mountainous tracts. Rainfall is the principal source of ground water replenishment. When rainfall occurs, it falls on the surface of the ground and depending on the porosity and permeability of the top soil surface it infiltrates and percolate to the ground. The porosity of the soil is the important factor for the rate of infiltration and percolation into the ground. After travelling some distance when it meets the rock surface the slope of the rock surface guides the flow and when this flow joins a rock crack, fault, fishers it starts filling the cavity of this crack or fault. Volume of these faults, fishers and cracks are the aquifers found in the mountainous region, off course there are certain perch aquifers also but most of the aquifers are vertical in nature in hills. These aquifers are source of springs, rivulet, ponds and rivers in the mountainous region. In the Tehri and Pauri Garhwal district, ground water flows out as springs and seepages where the water table intersects the ground surface. Ground water in the district occurs in fissured formations characterised by secondary porosity.

Ground water recharge techniques

(a) Applied technique

- Develop trenches

(b) Suggested techniques

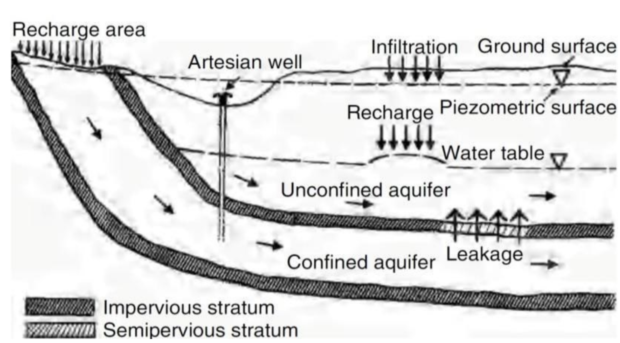
- Reducing surface runoff of rainfall and creating structures which could store water for a longer period
- Recharge of existing hand pump
- Rainwater harvesting system
- Recharge pit and shaft
- Vegetative cover
- Plants which have long root system can be helpful in plugging the cracks developed due to tectonic activities

ARTIFICAL RECHARGE- Artificial recharge refers to transfer of surface water to the aquifer by human interference. The natural process of recharging the aquifers is accelerated through percolation of stored or flowing surface water, which otherwise does not percolate into the aquifers.

Need for artificial recharge- Natural replenishment of ground water reservoir is a slow process and is often unable to keep pace with the excessive and continued exploitation of ground water resources This has resulted in declining ground water levels and depletion of springs, rivulets and ground water resources in such areas.

Advantages of artificial recharge

- Large subsurface storage space is available free of cost.
- Evaporation losses are negligible.
- Water Quality improvement by infiltration through the permeable media.
- It has no adverse social impacts such as displacement of population, loss of scarce agricultural land etc. as in the case of big dams.



- It is environment friendly, controls soil erosion and flood and provides sufficient soil moisture even during summer months
- Water stored underground is relatively immune to natural and man-made catastrophes.
- It provides a distribution system between recharge and discharge points
- Results in energy saving due to reduction in suction and delivery head as a result of water available at higher elevation and rise in water levels.

Process of Recharge

1. Recharge of underground aquifer is a slow and complex process. Rate of Infiltration varies from 5 ft per day to 5 ft per year.
2. Thus, the recharge though surface impounding to the aquifer is a very slow process and requires huge surface area with sufficient arrangements for impounding or reducing the rate of surface runoff, so that it could be facilitated for substantially recharging the underground aquifer.
3. As per slide no 04 The amount of shallow infiltration reduces from max. 25% to 10% with the paving or disturbing the natural ground surface. which means that under normal conditions max. 10-15% of total rainfall could be facilitated by human interventions for recharging the underground aquifer.
4. As per simple calculation, to sustain a discharge of only 1 LPM in a Spring over dry period of 100 days, we need an underground water storage of at least 2 Lakh litre. To sustain 10 LPM discharge, an underground water storage of 20 Lakh litre is needed. which will require a huge investment and a huge recharge area as well.
5. Due to rapid construction of road network and other developmental activities natural sub surface flow path, recharge area and cracks/faults/fishers of a rock surface get disturbed during road cutting. Thus, stopping the natural sub surface flow of water to the underground aquifer, resulting into depletion of Spring discharge.
6. The activities being done by different Agencies/Departments/Organisations has not revealed the desired results because of above reasons. The discharge of springs and rivulets are depleting gradually, which is a matter of grave concern, as Springs are the only life line for mountainous people.
7. As per reports of Uttarakhand Jal Sansthan, discharge of 40% water supply schemes constructed during last 5-10 years has depleted more than 50%.
8. This alarming situation demands an immediate effective plan of action for recharging these aquifers before the connected springs & rivulets become complete dry. The depletion in recharge of our aquifers has adversely affected the performance of Hand pumps also and there is a need to recharge these Hand pumps also for their long-term sustainability.

Workshop in Tehri Garhwal – Block Office Chamba (Uttarakhand)

The workshop was conducted on 7th November 2022 in the conference hall at block office of Chamba. 30 members along with Para workers from Moldhar, Kadukhal & Kotigad water shed participated in the workshop. BDO participated in the workshop and listened to the community members' experiences while spring shed work.

The workshop started with a brief address by Dr. Vartika Singh (Co-PI). Vartika welcomed the participants for the workshop and gave them an overview of the discussion to be done. Later, Dr. Maya Kumari (Co-PI) shared the objective of the workshop and he also mentioned how springs in Uttarakhand are drying and why community participated spring shed is important.

Later a springs-based presentation was done and discussion was moved forward by Mr. J.C. Kala former DG of forest, in government of India. Mr. Kala and Prof. Madhusoodanan facilitated the session and had a dialogue with the community members over need of Spring Shed Management and their experiences while work. He also added his experience of natural resource management while being in the department. A short documentary was played to understand the work on Spring shed in the Garhwal region.

After the discussion on film few questions based on spring shed management were answered by the participants. Later, members of the project team addressed the participants. All the participants thanked the project team for conducting this workshop as they were able to understand the details of the work and about the organization who supported them for their work.

Saraswati Kothari from Moldhar said "The trenches made by WUG members helped in increasing the discharge of their spring while it gets dry in summers"

Prakash, the president of WUG said, "Collective work by their village and it's positive impact on the springs has proved that anything is possible with united work"

Photos of Community workshop at Tehri Garhwal District


पर कार्यशाला
नवम्बर 7, 2022

Workshop at Gumkhal (Pauri Garhwal)

This one-day workshop on community- based spring shed management was organized in Gumkhal on 9th November 2022. 22 Members of Ghurdauri, Malan and Bareth Watershed participated in the workshop with their para workers.

The workshop was started with a brief introduction by the project team. Later, the objective of the workshop was shared by Dr. Vartika Singh (Co-PI). She mentioned the importance of community participation in sustaining the works done for springs. Later Dr. Maya Kumari (Co-PI) shared a presentation on spring shed management giving a brief overview of each spring of both the watershed areas. In the end of the presentation a small documentary film was played and few questions were asked to the participants based on their experiences.

The workshop ended with the address by Prof. Madhusoodanan & J.C. Kala; they said that their support to the spring shed work is limited while community contribution is a continuous part to keep the springs recharged and clean.

The participants said that they feel very happy after working for their springs and they look forward for getting support in future in terms of trainings and guidance.

Nandan Mohan Kala said, “We didn’t know about the catchment area of our springs. The project team helped us in identifying the recharge area and now we will try to keep it clean and regular cleaning of the trenches will be done by WUG members for having regular availability of water in our spring”

Photos of Community workshop at Pauri Garhwal District

Climate of the Garhwal region

The Garhwal region is characterized by its diverse topography, ranging from the lower foothills to the majestic Himalayan peaks. The study examines temperature trends, precipitation patterns, extreme weather events, and their implications for the region's ecosystems, water resources, agriculture, and livelihoods. Understanding the historical climate trends is crucial for developing effective adaptation and mitigation strategies in the face of ongoing climate change.

Observations over the past century reveal a warming trend in the Garhwal region. The warming trend is more pronounced at higher elevations, affecting both daily minimum and maximum temperatures. This region experiences a diverse range of precipitation patterns due to its varying elevations. The region's lower foothills receive a significant amount of rainfall during the monsoon season, while higher altitudes experience snowfall during the winter months. Long-term precipitation data shows interannual variability, with some years receiving above-average rainfall and others experiencing deficits. Garhwal is susceptible to extreme weather events such as cloudbursts, flash floods, and landslides, particularly during the monsoon season. Studies indicate an increasing frequency of such events in recent years, which can have devastating impacts on communities, infrastructure, and natural ecosystems.

The observed changes in temperature and precipitation patterns have significant implications for the region's ecosystems. The warming trend affects the timing of plant phenology, alters species distributions, and influences the health of forests and alpine meadows. The shifts in climate can also disrupt critical ecological processes, such as pollination and seed dispersal, potentially leading to changes in biodiversity. Water resources in Garhwal largely depend on the timing and magnitude of snow and glacier melt. The observed warming trend has accelerated glacier retreat, affecting the timing and flow of rivers. Additionally, changing precipitation patterns can lead to changes in the recharge of groundwater and the availability of surface water resources. Agriculture is a crucial sector in the Garhwal region, supporting the livelihoods of a significant portion of the population. The observed changes in temperature and precipitation can influence crop yields, planting patterns, and agricultural practices. Changes in water availability also pose challenges for irrigation and crop planning.

The observed climate trends in Garhwal indicate an increased risk of natural hazards, including landslides, glacial lake outbursts, and forest fires. These events can have severe implications for infrastructure, communities, and the environment, necessitating robust risk reduction and disaster management strategies.

Climate projections and analyses for the near-future

Regional climate projections play a pivotal role in understanding and preparing for the impacts of climate change at a local level. As global temperatures continue to rise, it is becoming increasingly evident that climate change has far-reaching consequences, affecting various aspects of ecosystems, economies, and human well-being. Regional climate projections provide valuable insights into how specific areas will experience climate change, enabling policymakers, communities, and businesses to develop informed adaptation and mitigation strategies. This study attempts to emphasize the importance of regional climate projections in addressing the challenges posed by climate change and fostering sustainable development. Regional climate projections offer a finer level of detail compared to global climate models. Understanding how climate change will manifest at a local level allows stakeholders to tailor adaptation strategies to the specific challenges faced by their region. Different regions may experience varying impacts, such as changes in precipitation patterns, extreme weather events, sea-level rise, or shifts in ecosystems. By having access to regional projections, decision-makers can prioritize interventions, allocate resources effectively, and develop climate-resilient policies tailored to the unique characteristics of their area.

Assessing the vulnerabilities and risks associated with climate change is crucial for managing its impacts. Regional climate projections provide critical data that helps identify areas and sectors most at risk. For instance, coastal regions might be vulnerable to sea-level rise and increased storm surges, while mountainous areas may face heightened risks of glacial melt and associated hazards. Armed with this knowledge, governments, businesses, and communities can adopt proactive measures to protect infrastructure, ecosystems, and livelihoods.

Incorporating regional climate projections into planning and decision-making processes is vital for promoting sustainable development. These projections offer insights into how climate change can interact with other socio-economic and environmental factors, helping to avoid maladaptation and unintended consequences. For example, when designing urban infrastructure, regional climate projections can inform decisions about the location and design of buildings to minimize exposure to extreme temperatures and flooding. Integrating climate projections into land-use planning can also help safeguard valuable ecosystems and natural resources.

Empowering societies to build resilience against climate-related risks is crucial. By understanding how climate change will unfold in their specific area, communities can adopt measures such as improving water management, implementing early warning systems for extreme events, and enhancing disaster preparedness. Resilience-building measures contribute to reducing vulnerabilities and minimizing the impacts of climate change on human lives and livelihoods. It is also of significant importance to businesses and industries, enabling them to assess potential risks and opportunities. For example, agriculture industries can use climate projections to adjust crop choices and planting times to cope with changing temperature and precipitation patterns. Energy providers can plan for increased energy demand during heatwaves, and coastal businesses can prepare for sea-level rise and its effects on infrastructure and supply chains.

Downscaling of regional climate

The Garhwal region is characterized by its diverse landscapes, ranging from low-lying valleys to towering Himalayan peaks. As climate change continues to pose significant challenges to local ecosystems, water resources, agriculture, and communities, it becomes crucial to understand the region's specific climate impacts. Downscaling, a technique used to translate coarse-resolution global climate model data into higher-resolution local projections, plays a pivotal role in providing actionable climate information for the Garhwal region.

Capturing Local Climate Variability

Global climate models provide essential information about the Earth's climate system, but their coarse resolution often fails to capture the intricacies of regional climate variability. The Garhwal region's complex topography and diverse microclimates necessitate higher-resolution data to understand how climate change will manifest at a local scale. Downscaling bridges this gap by utilizing historical climate observations and patterns to create region-specific projections, allowing stakeholders to grasp the localized nuances of temperature, precipitation, and other climatic variables.

Enhancing Climate Change Projections:

Downscaling improves the accuracy and reliability of climate change projections for the Garhwal region. By combining global climate model output with localized observations, downscaling methods provide more robust predictions of future climatic conditions, including seasonal shifts, extreme events, and long-term trends. These projections are vital for assessing the region's vulnerabilities to climate change and devising effective adaptation and mitigation strategies.

Supporting Sectoral Decision-Making

Various sectors in the Garhwal region, such as agriculture, water management, and tourism, rely heavily on climate-sensitive resources and activities. Accurate climate projections through statistical downscaling are indispensable for informed decision-making across these sectors. For instance, agricultural stakeholders can use downscaled data to adjust planting schedules, choose appropriate crop varieties, and implement efficient water management practices in response to projected changes in temperature and precipitation. Similarly, water managers can use downscaled data to assess future water availability and plan for potential shifts in hydrological patterns.

Evaluating Climate Risks and Vulnerabilities

The diverse climate-related risks faced by this region include glacier melt, changing monsoon patterns, and extreme weather events. Downscaling facilitates a detailed assessment of climate risks and vulnerabilities, allowing for targeted adaptation measures. It helps identify specific areas and communities most at risk and assists in devising customized resilience-building strategies, minimizing the potential socio-economic impacts of climate change.

Facilitating Local Participation and Engagement

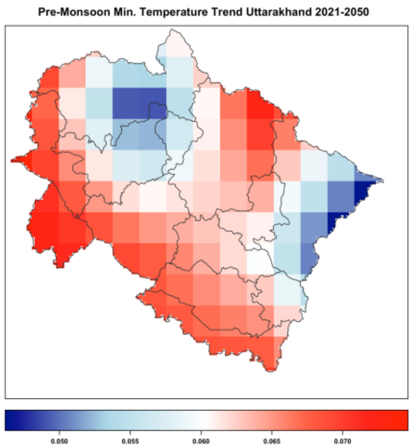
Local communities in the Garhwal region possess valuable traditional knowledge and lived experiences of climate impacts. Downscaling allows scientists and researchers to incorporate this indigenous knowledge into climate models, enhancing the accuracy and relevance of the projections. Involving local communities in the downscaling process also fosters ownership and empowerment, promoting better climate-related decision-making and fostering more inclusive and sustainable adaptation strategies.

In this study, the climate change projections from BCC-CSM2-HR model which is a high-resolution version of the Beijing Climate Center (BCC) Climate System Model (T266 in the atmosphere and 0.25° latitude × 0.25° longitude in the ocean) of the CMIP-5 (Coupled Model Intercomparison Project) – SSP2-4.5 (Shared Socio-economic Pathways) scenario has been downscaled for the State of Uttarakhand and analysed. SSPs are shared socio-economic pathways of projected socio-economic global changes up to year 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies. Analyses of the major climate variables in different seasons were carried out in this study for the near-future (2021-2050).

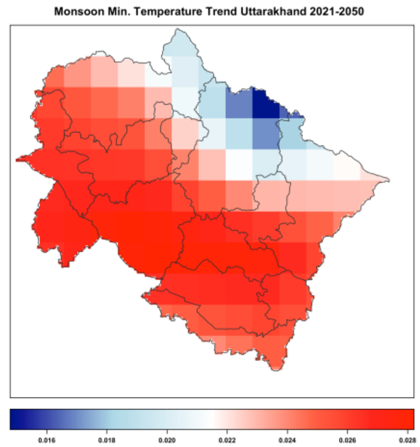
Minimum Temperature Projections

Minimum temperature projections for the State of Uttarakhand indicate a potential increase in nighttime temperatures in the coming decades (Figure 7). Tehri Garhwal (Figure 8) and Pauri Garhwal (Figure 9) also show similar trends. Warmer nights can impact agriculture by affecting the vernalization process of certain crops, leading to changes in flowering and fruiting patterns. Moreover, higher minimum temperatures can disrupt the natural hibernation and migration patterns of wildlife, affecting biodiversity and ecological balance. For the tourism sector, warmer nights may alter the comfort levels for visitors, impacting their sleep quality and overall experience. Additionally, higher minimum temperatures can exacerbate heat stress for vulnerable populations, such as the elderly and those with pre-existing health conditions, necessitating improved heat adaptation strategies and healthcare services.

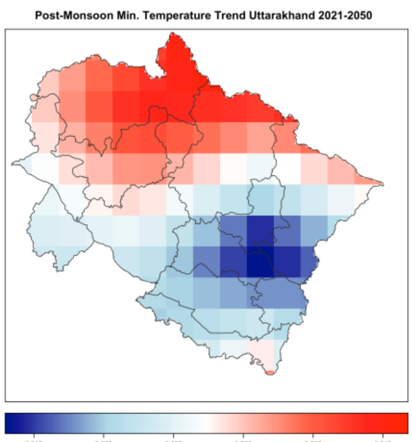
Pre-monsoon



Monsoon



Post-monsoon



Winter

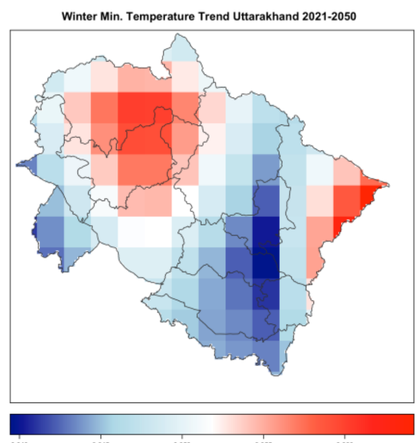
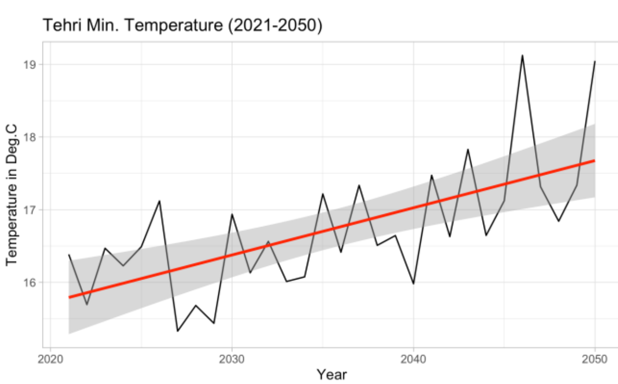
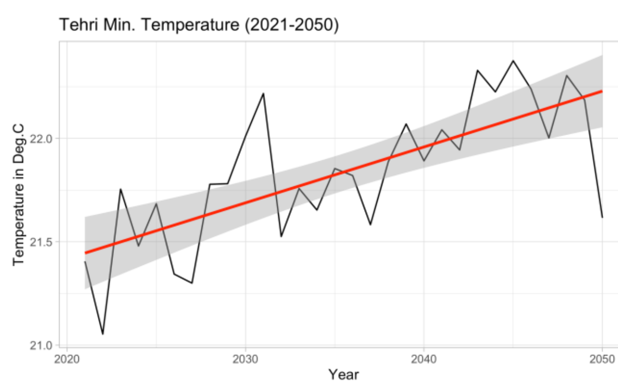


Figure 7. Minimum temperature trend – Uttarakhand (2021-2050)

Pre-monsoon



Monsoon



Post-monsoon

Winter

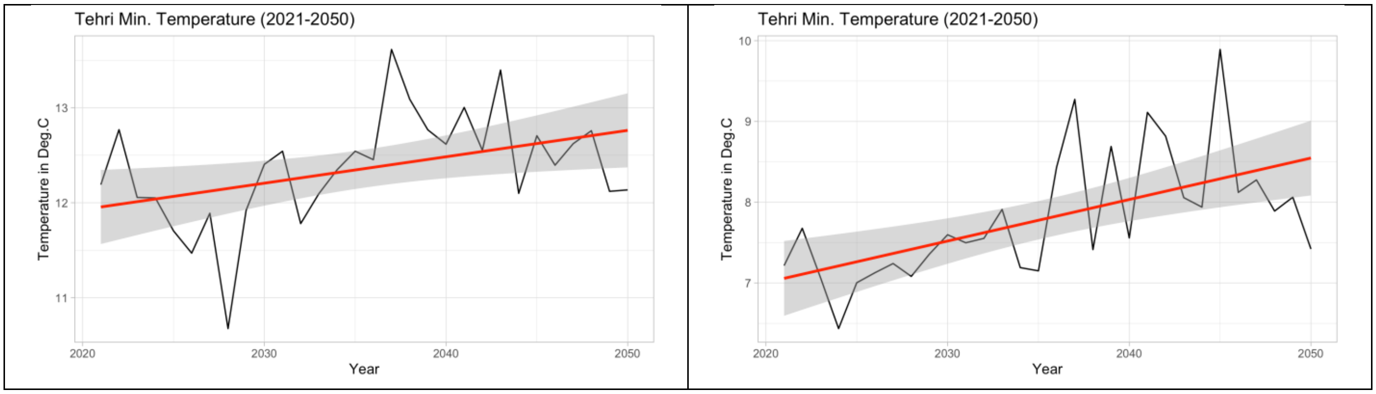


Figure 8. Minimum temperature trend – Tehri Garhwal (2021-2050)

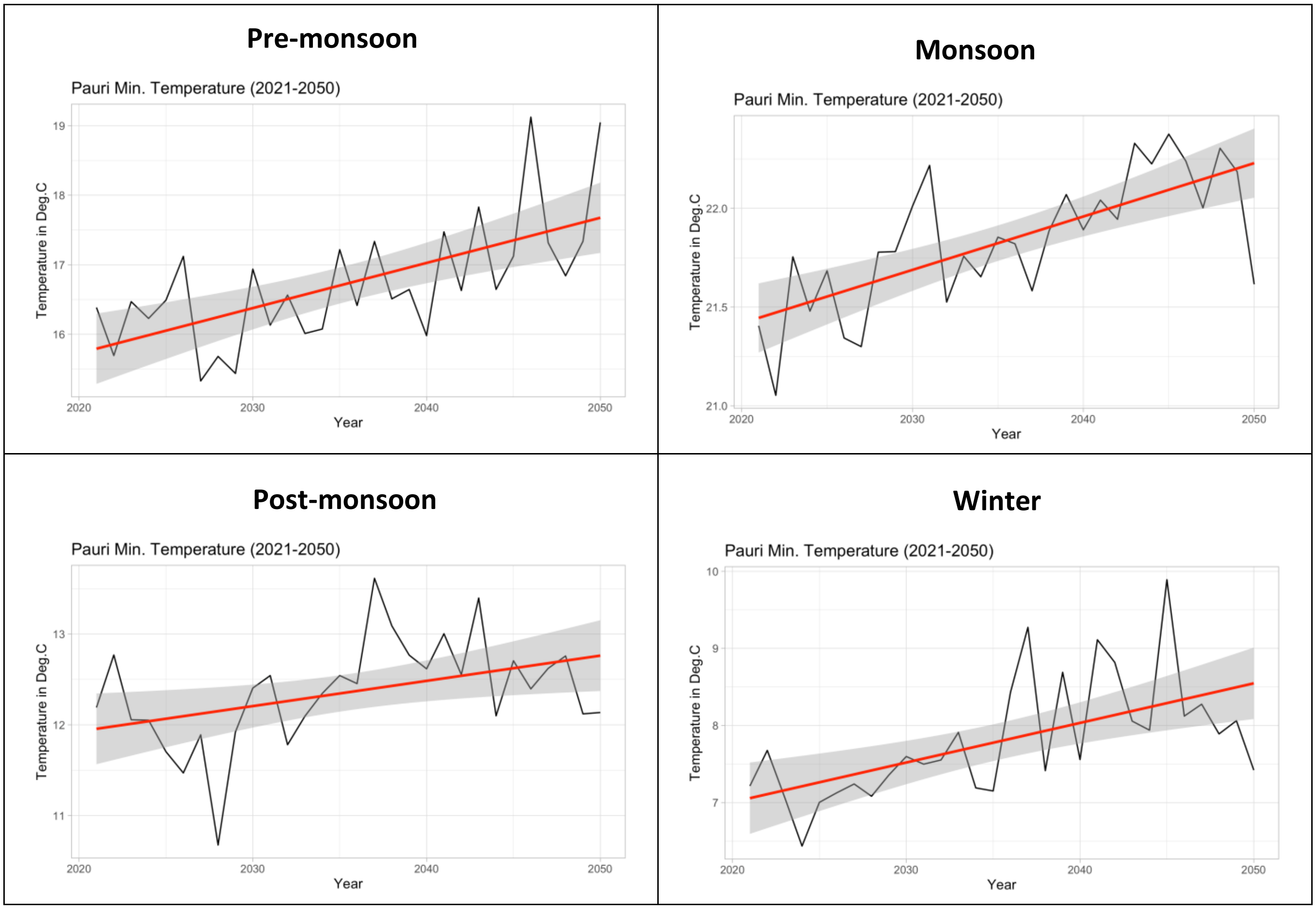
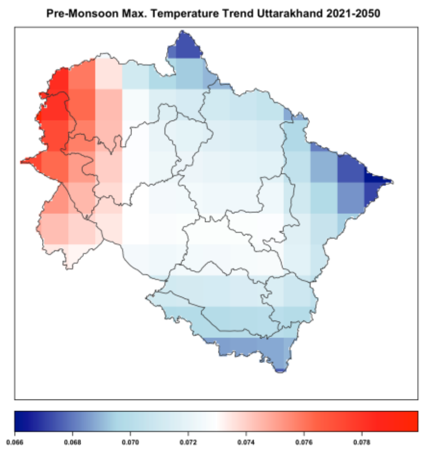


Figure 9. Minimum temperature trend – Pauri Garhwal (2021-2050)

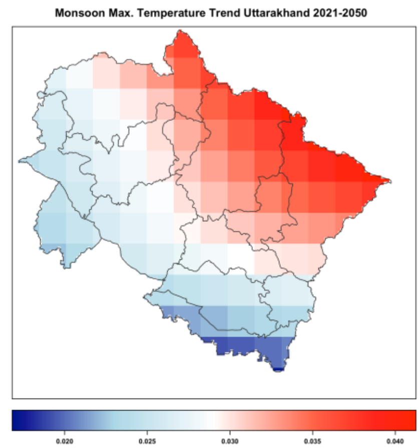
Maximum Temperature Projections

Maximum temperature projections for the Garhwal region indicate a rise in daytime temperatures (Figure 10). The trend in maximum temperature for Tehri Garhwal and Pauri Garhwal regions are shown in Figure 11 and Figure 12 respectively. This increase in extreme heat events can have severe implications for agriculture. Heat stress can lead to reduced crop yields and even crop failures. It may also increase the demand for irrigation, potentially straining water resources and exacerbating existing water scarcity issues. In the tourism sector, higher maximum temperatures might discourage outdoor activities during peak heat hours, impacting adventure tourism and pilgrimage visits. Additionally, extreme heat can put stress on local infrastructure, such as transportation systems and energy grids, necessitating investments in heat-resilient infrastructure.

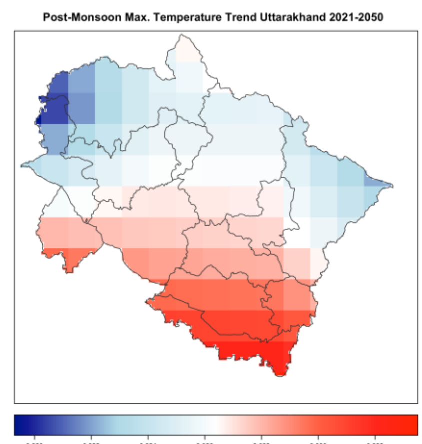
Pre-monsoon



Monsoon



Post-monsoon



Winter

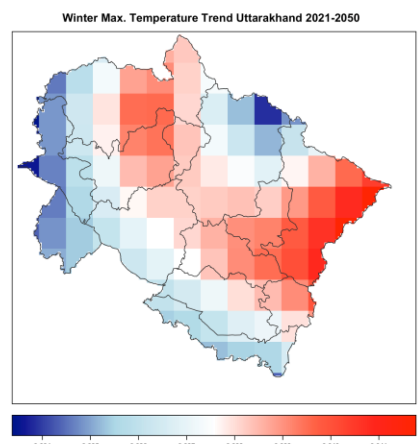
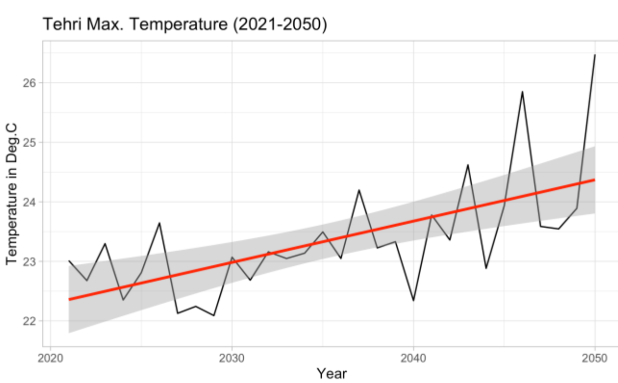
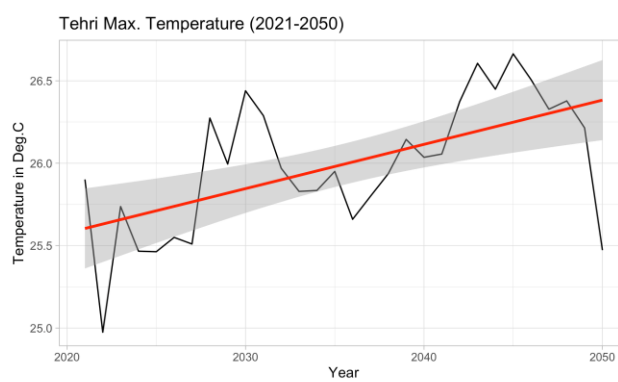


Figure 10. Maximum temperature trend – Uttarakhand (2021-2050)

Pre-monsoon



Monsoon



Post-monsoon

Winter

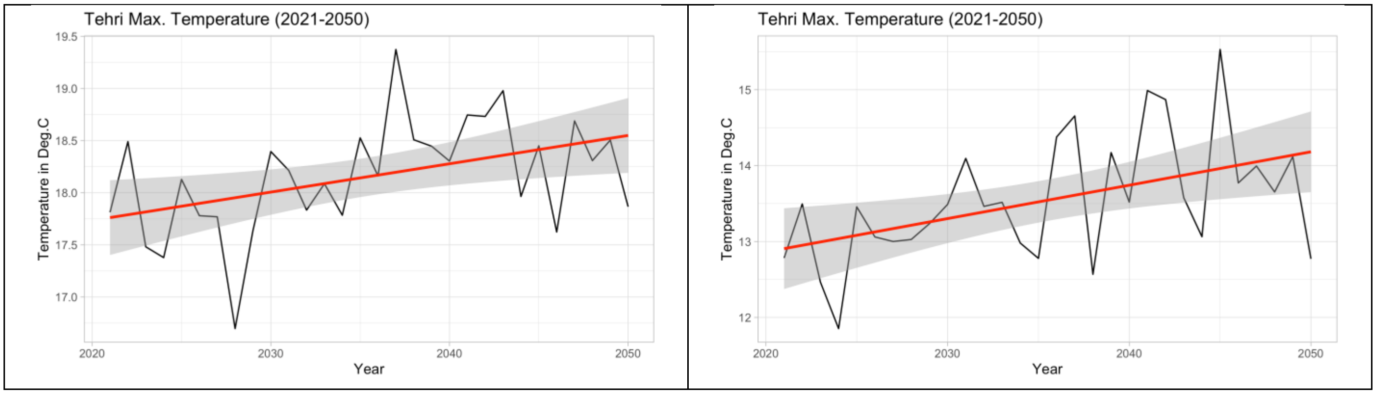


Figure 11. Maximum temperature trend – Tehri Garhwal (2021-2050)

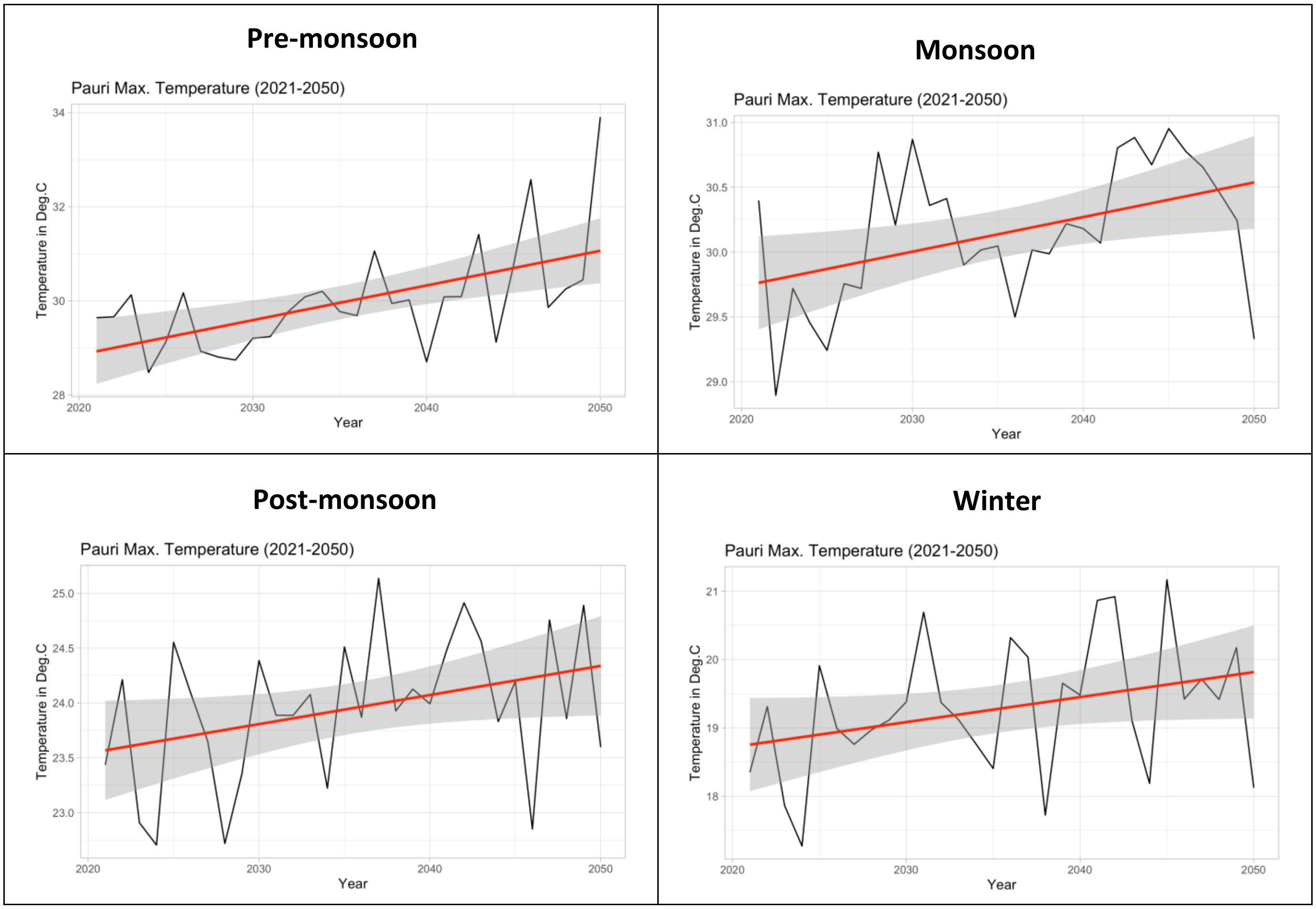
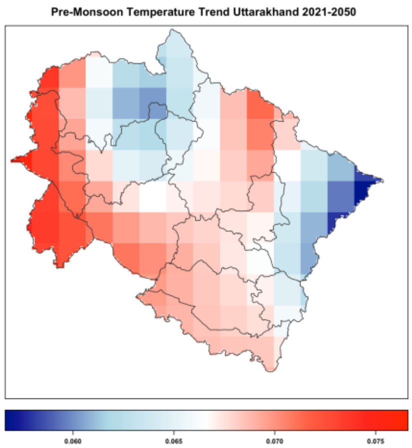


Figure 12. Maximum temperature trend – Pauri Garhwal (2021-2050)

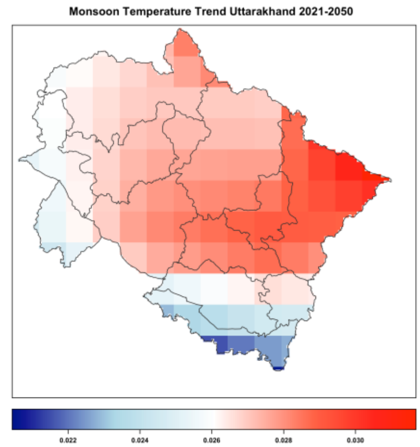
Mean Temperature Projections

Mean temperature projections, representing the average of minimum and maximum temperatures, provide an overall picture of the region's changing climate (Figure 13).). The trend in mean temperature for Tehri Garhwal and Pauri Garhwal regions are shown in Figure 14 and Figure 15 respectively. With rising mean temperatures, the growing seasons for crops may alter, influencing the choice of crops and farming practices in the Garhwal region. This shift can also affect the phenology of plants and animals, disrupting delicate ecological relationships. In terms of water resources, changes in mean temperatures can affect snowmelt patterns and river flows, impacting the timing and availability of water for various sectors. Furthermore, changes in the mean temperature can influence disease patterns, with potential implications for public health and healthcare infrastructure.

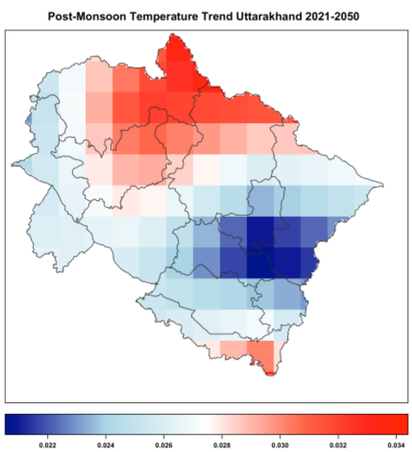
Pre-monsoon



Monsoon



Post-monsoon



Winter

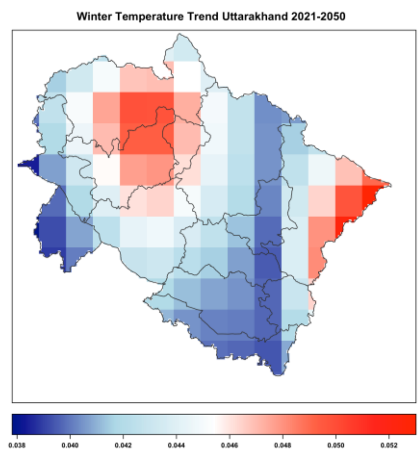
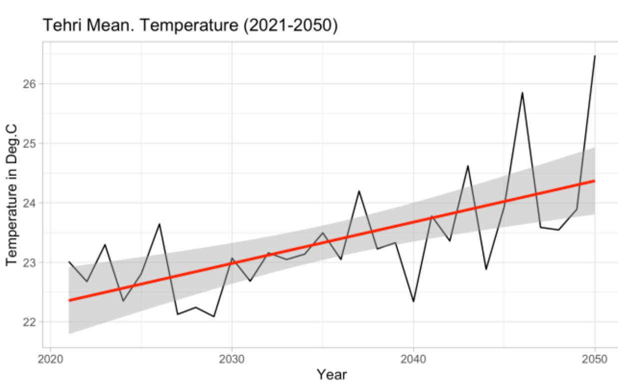
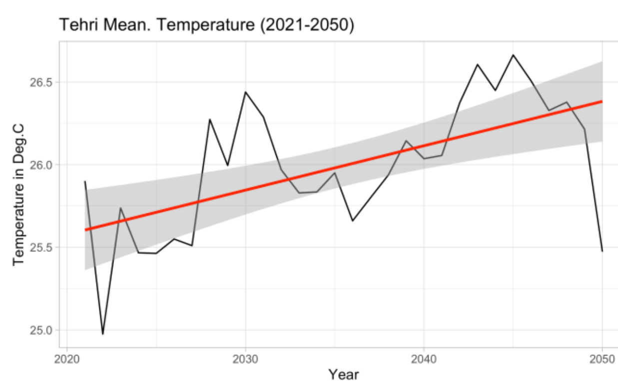


Figure 13. Mean temperature trend – Uttarakhand (2021-2050)

Pre-monsoon



Monsoon



Post-monsoon

Winter

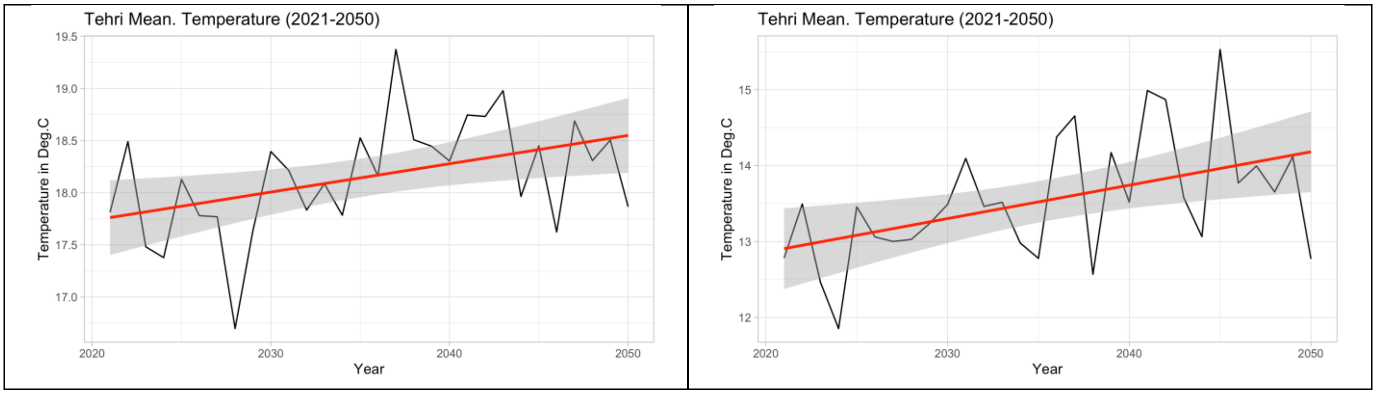


Figure 14. Mean temperature trend – Tehri Garhwal (2021-2050)

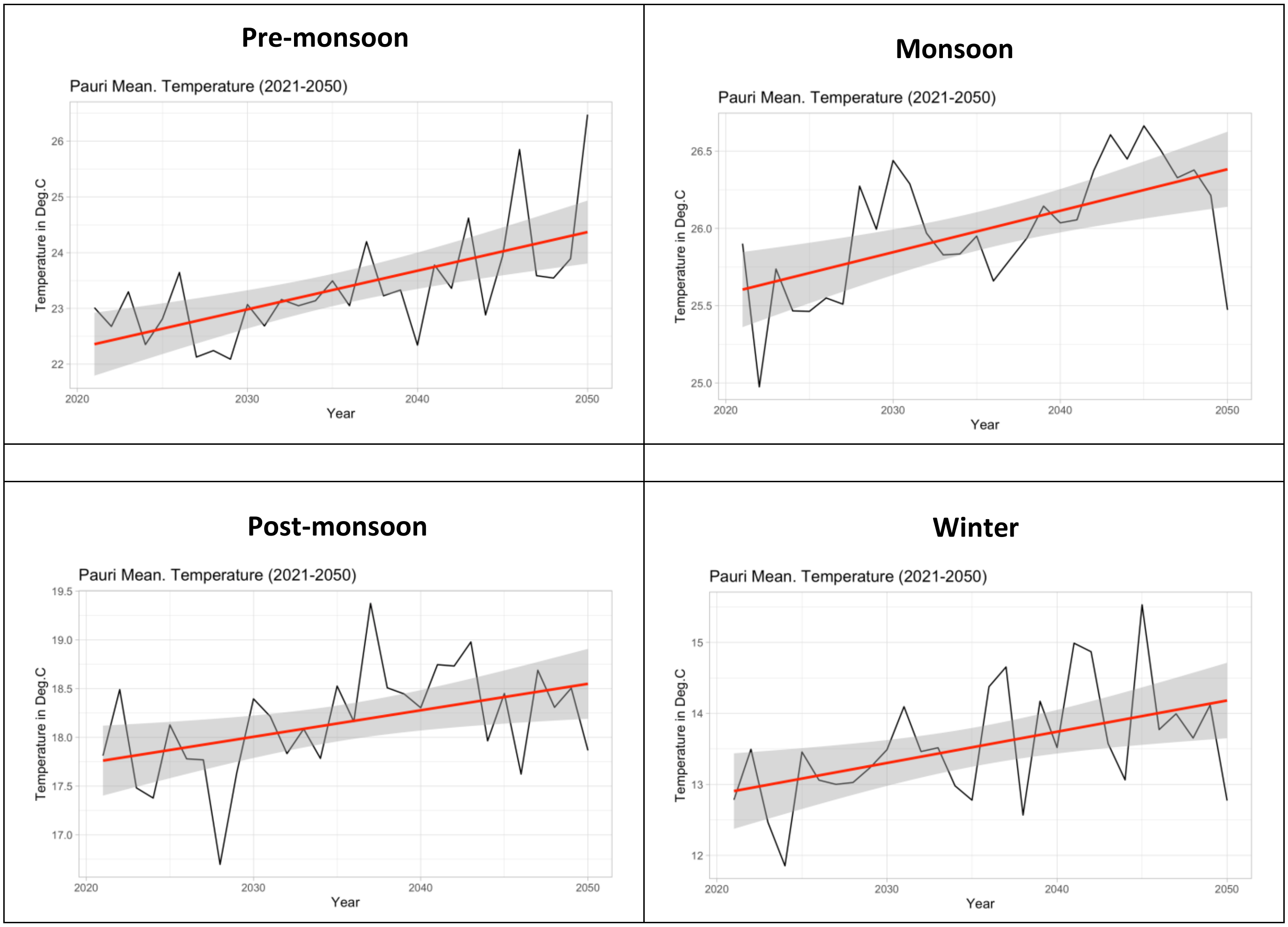


Figure 15. Mean temperature trend - Pauri Garhwal (2021-2050)

Temperature projections for the State of Uttarakhand region suggest an overall trend of increasing temperatures, impacting different sectors in various ways. The agriculture sector may face challenges with altered growing seasons, crop selection, and water management. The water resources sector may encounter changes in river flows and increased demand for irrigation. The tourism sector might experience shifts in visitor preferences and comfort levels. It is essential for the local government, communities, and stakeholders to collaborate on adaptation and mitigation strategies to address these challenges effectively. Sustainable practices, improved infrastructure, and robust policies are key to building resilience and ensuring the region's socio-economic and environmental well-being in the face of a changing climate.

Rainfall Projections

Rainfall projections (Figure 16) for the State of Uttarakhand have significant implications for water resources, including mountain springs, and various other sectors. As climate change alters precipitation patterns, it can lead to both challenges and opportunities for the region's water availability and other sectors.

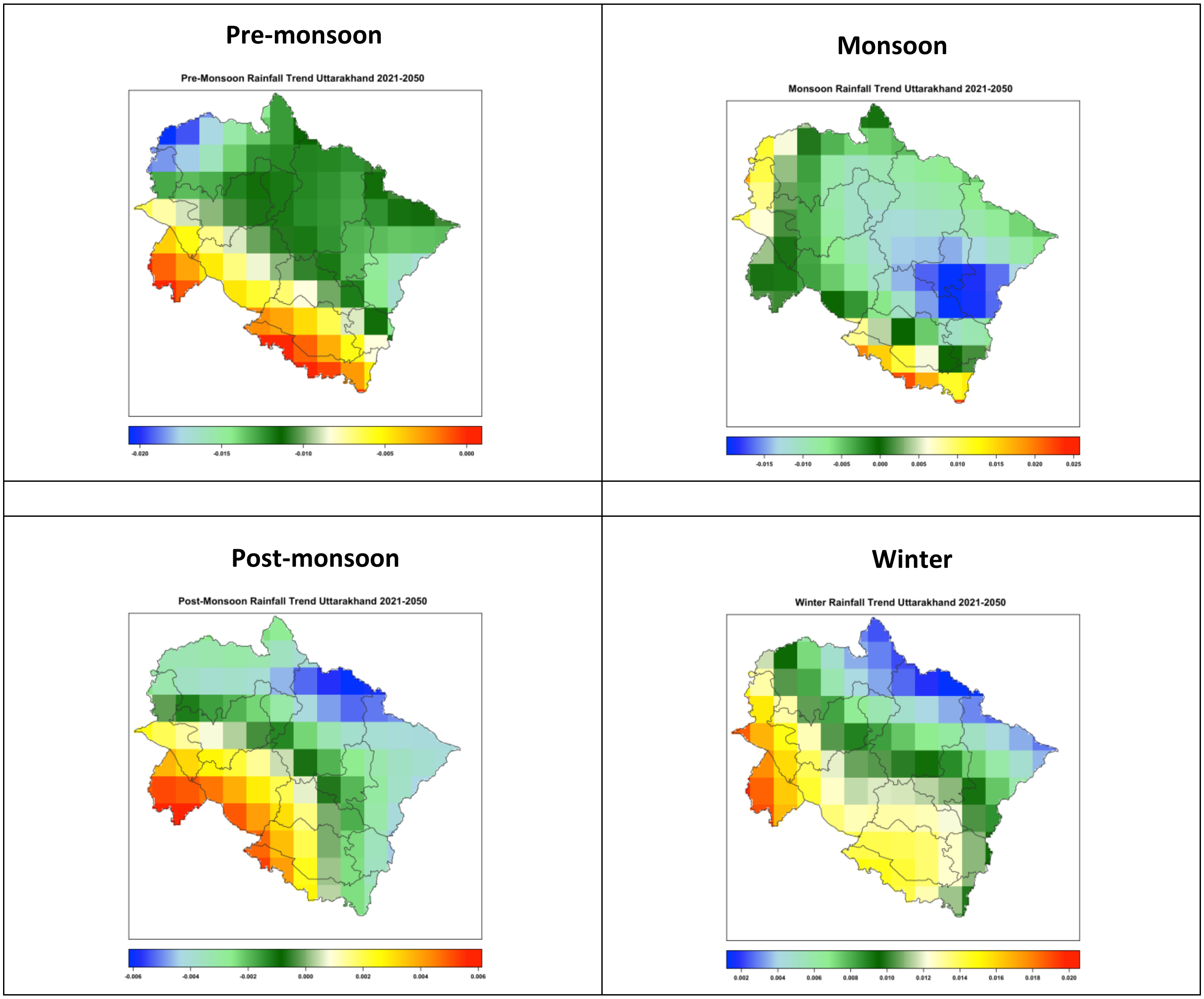


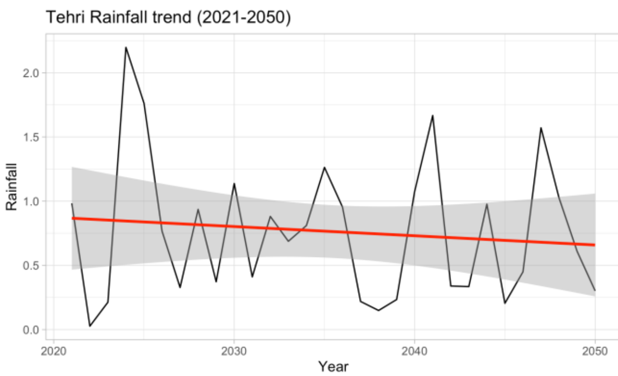
Figure 16. Rainfall trend - Uttarakhand (2021-2050)

The diverse and varied topography influence the rainfall patterns of the State of Uttarakhand. The region experiences both the southwest monsoon and the northeast monsoon, which bring the majority of the annual rainfall. The southwest monsoon (June to September) is the primary rainy season, providing the bulk of the precipitation in the State. Projections indicate that Uttarakhand is expected to experience changes in rainfall patterns due to climate change. While specific projections can vary based on different models and scenarios, some general trends can be observed.

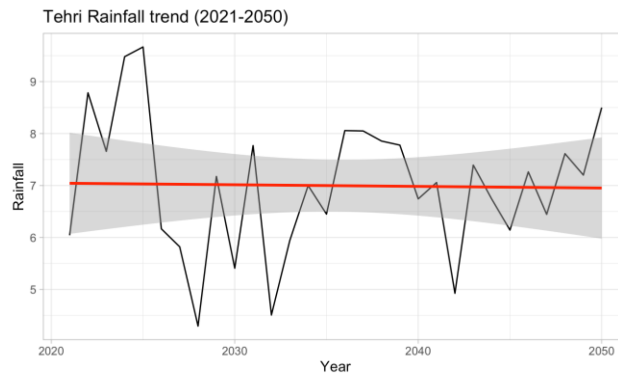
Overall Increase in Mean Annual Rainfall: Projections suggest that Uttarakhand may experience an increase in mean annual rainfall in the 21st century. This could result from various factors, including changes in atmospheric circulation patterns and the intensification of the monsoon.

Seasonal Variability: While there might be an overall increase in annual rainfall, the distribution of rainfall across seasons may change (Figure 17, Figure 18). Projections indicate that the southwest monsoon might become more intense, leading to heavier and more concentrated rainfall during the monsoon season. At the same time, the northeast monsoon may also see changes in its intensity and distribution.

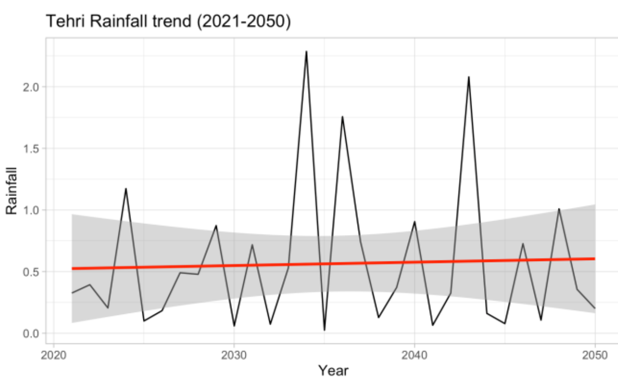
Pre-monsoon



Monsoon



Post-monsoon



Winter

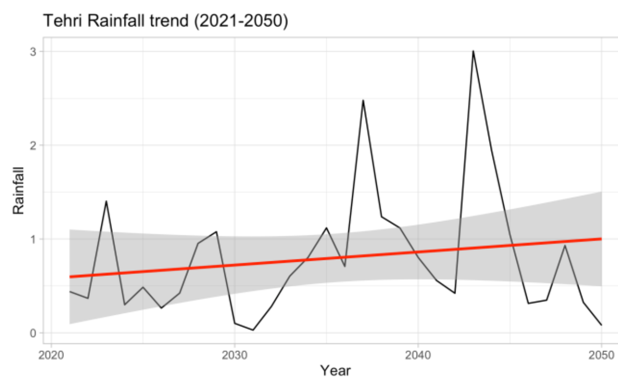
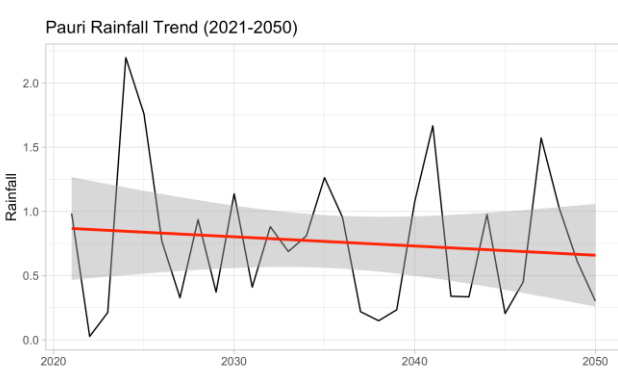
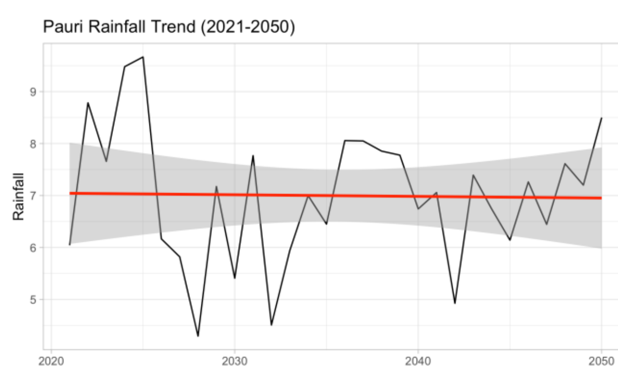


Figure 17. Rainfall trend – Tehri Garhwal (2021-2050)

Pre-monsoon



Monsoon



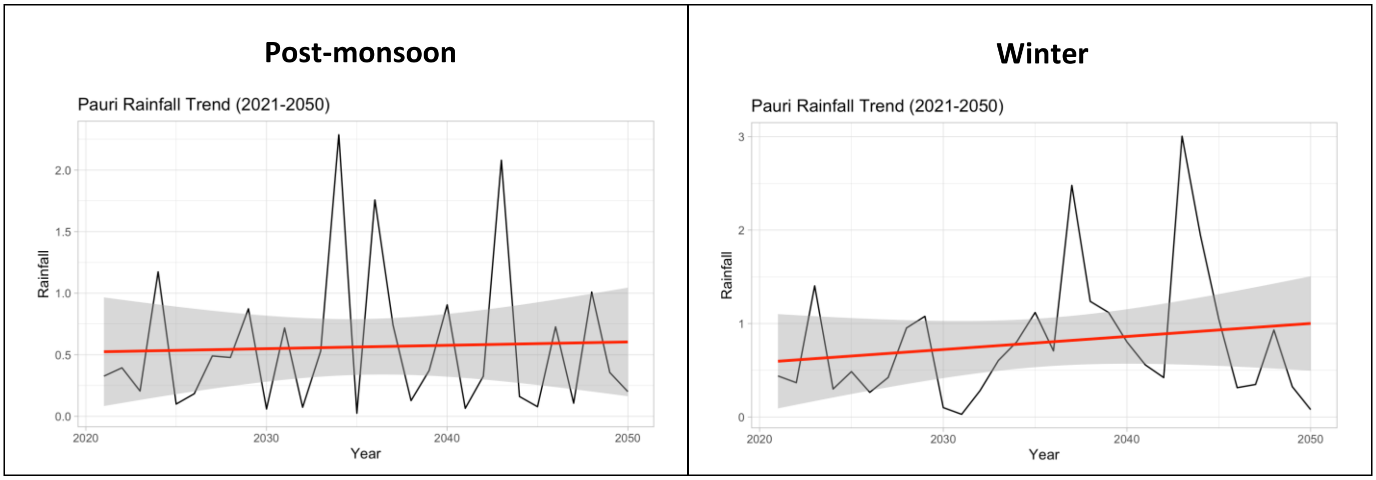


Figure 18. Rainfall trend – Pauri Garhwal (2021-2050)

Climate projections also suggest an increase in the frequency and intensity of extreme rainfall events, such as heavy downpours and intense storms. These events can lead to flash floods, landslides, and other natural disasters, posing risks to human settlements and infrastructure. It is crucial to note that climate projections come with uncertainties, and regional variations can be significant. Local topography, altitude, and other regional factors can influence rainfall patterns in specific areas within Uttarakhand.

Rainfall projections are crucial for understanding the future availability and distribution of water resources in the Garhwal region. Changes in rainfall patterns can impact river flows, groundwater recharge, and the overall hydrological cycle. Decreased rainfall may lead to reduced river flows and lower water levels in lakes and reservoirs, affecting water supply for agriculture, industry, and domestic use. As a result, water scarcity could become a pressing issue, particularly during dry periods. This can have socio-economic implications and may necessitate improved water management strategies, water conservation efforts, and sustainable water use practices.

The Garhwal region is known for its mountain springs, which are vital sources of freshwater for communities and ecosystems. Rainfall projections are crucial for understanding the potential changes in these springs. Decreased rainfall or alterations in the timing of precipitation events may impact the recharge of mountain springs, leading to reduced flow rates or even the drying up of some springs. This can have severe consequences for the availability of clean drinking water and can affect the livelihoods of communities that depend on these springs for their water needs. Conservation efforts, protection of catchment areas, and sustainable water use are essential to preserve these valuable mountain springs in the face of changing precipitation patterns.

Rainfall projections have significant implications for the agriculture sector in the Garhwal region. Changes in precipitation can affect soil moisture levels, crop water requirements, and overall agricultural productivity. Projections of altered rainfall patterns may result in shifting growing seasons, changes in crop choices, and adjustments in irrigation practices. Farmers may need to adopt drought-resistant crop varieties and water-efficient irrigation techniques to cope with changing water availability. Additionally, extreme rainfall events can lead to soil erosion and crop damage, necessitating the implementation of soil conservation measures and disaster preparedness strategies.

The Garhwal region has considerable hydropower potential, and rainfall projections are vital for planning and managing hydropower resources. Changes in precipitation patterns can affect the inflow into rivers and reservoirs, impacting the efficiency of hydropower plants. Reduced water availability during dry periods may lead to lower electricity generation capacity, affecting energy security. Hydropower operators and policymakers will need to incorporate rainfall projections into their long-term planning and resource management to ensure a reliable and sustainable energy supply.

Climate change-induced shifts in precipitation patterns can pose challenges to water availability and management, affecting various sectors' functioning and livelihoods. Adapting to these changes will require integrated and sustainable approaches that prioritize water conservation, efficient resource management, and climate-resilient practices across sectors.

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