Template/Pro forma for Submission

NMHS-Himalayan Institutional Fellowship Grant

FINAL TECHNICAL REPORT (FTR)

NMHS Reference No.:	GBPNI/NMHS-2018-19/HSF28-06/	**Date of Submission:**	2	7	0	3	2	0	2	3
			d	**d**	**m**	**m**	**y**	**y**	**y**	**y**

FELLOWSHIP TITLE (IN CAPITAL)

A WOMEN CENTRIC APPROACH TO IDENTIFY THE FACTORS GOVERNING THE WATERSHED INTEGRITY AND MULTI-HAZARD SUSCEPTIBILITY IN SELECTED DISTRICTS OF THE UTTARAKHAND

Sanctioned Fellowship Duration: *from* (**19.12.2018**) *to* (**18.12.2021**).

Extended Fellowship Duration (if applicable): *from* (19.12.2021) *to* (30.05.2022).

***Submitted to*:**

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***Submitted by*:**

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GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to be commenced from the date of start of the Institutional Fellowship (as per the Sanction Order issued at the start of the Fellowship) till its completion. Each detail has to comply with the NMHS Sanction Order.
2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset process. Colored Photographs (4-5 good action photographs), tables and graphs should be accommodated within the report or should be annexed with captions. Sketches and diagrammatic illustrations may also be given giving step-by-step details about the methodology followed in technology development/modulation, transfer and training. Any correction or rewriting should be avoided. Please give information under each head in serial order.
3. Training/ Capacity Building Manuals (with detailed contents of training programme, technical details and techniques involved) or any such display material related to fellowship activities along with slides, charts, photographs should be sent at the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.
4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time-to-time, so each section of the NMHS-FTR needs to duly filled by the Fellowship Coordinator/ PI and verified by the Head of the Implementing Institution/ University.
5. Five (5) bound hard copies of the NMHS-Institutional Fellowship Final Technical Report (FTR) and a soft copy should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand** *via* e-mail nmhspmu2016@gmail.com.

The FTR is to be submitted into following two parts:

Part A – Cumulative Fellowship Summary Report

Part B – Comprehensive Report

Following Financial and other necessary documents/certificates need to be submitted duly signed and verified along with Final Technical Report (FTR):

Annexure I	Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE), including interest earned for the last Fiscal year including the duly filled GFR-19A (with year-wise break-up)
Annexure II	Consolidated Interest Earned Certificate
Annexure III	Consolidated Manpower Certificate and Direct Benefit Transfer (DBT) Details showing the education background, i.e. NET/GATE etc. qualified or not, Date of joining and leaving, Salary paid per month and per annum (with break up as per the Sanction Order and year-wise).
Annexure IV	Details and Declaration of Refund of Any Unspent Balance as Real-Time Gross System (RTGS) in favor of NMHS GIA General
Annexure V	Details of Technology Transfer and Intellectual Property Rights developed.

NMHS-Final Technical Report (FTR) *template*

NMHS- Institutional Himalayan Fellowship Grant

DSL: *Date of Sanction Letter Completion*

d	d	m	m	y	y	y	y

DFC: *Date of Fellowship*

d	d	m	m	y	y	y	y

Part A: <u>CUMULATIVE SUMMARY REPORT</u>

<u>(to be submitted by the Coordinating Institute/Coordinator)</u>

1. Details Associateship/Fellowships

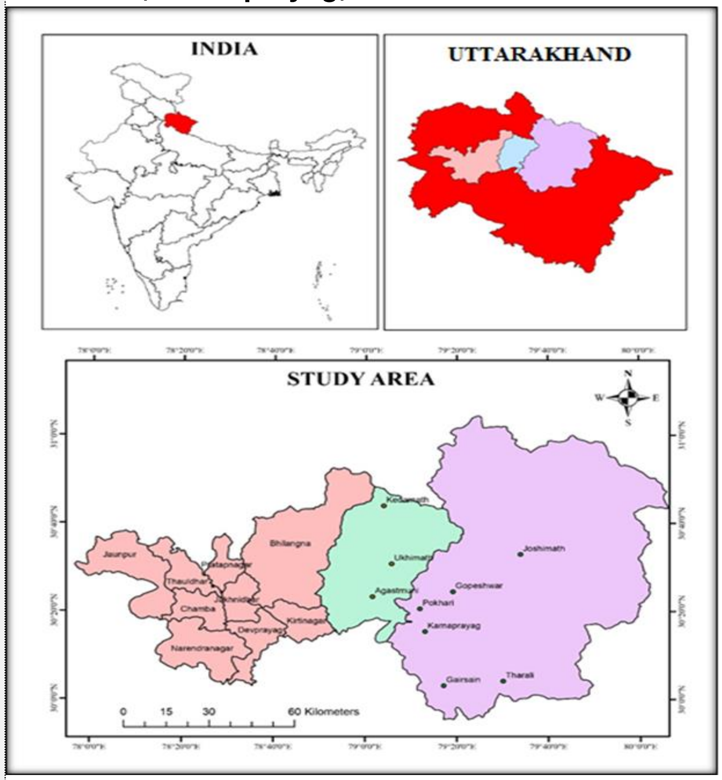
1.1 Contact Details of Institution/University

NMHS Fellowship Grant ID/ Ref. No.:	GBPNI/NMHS-2018-19/HSF28-06/
Name of the Institution/ University:	Guru Gobind Singh Indraprastha University, Dwarka, Sector 16, New Delhi-110078
Name of the Coordinating PI:	Professor Varun Joshi
Point of Contacts (Contact Details, Ph. No., E-mail):	Contact No.: 9971122817 E-mail: varunj63@gmail.com

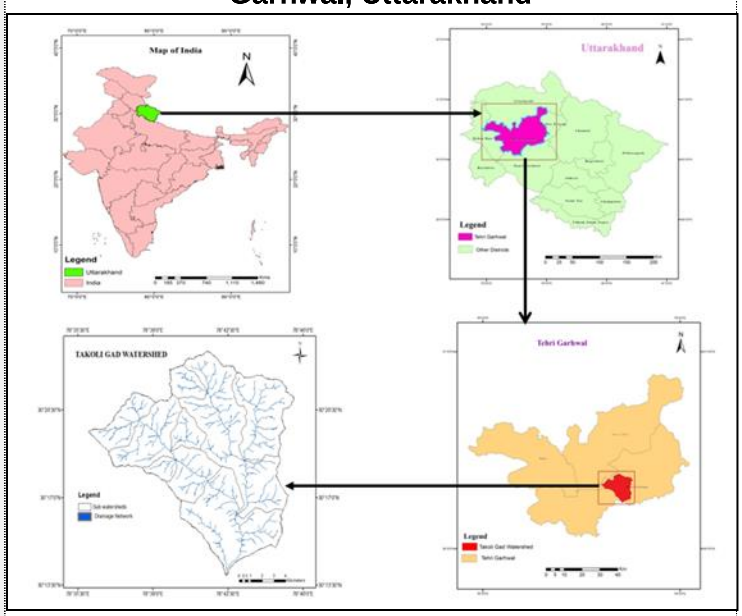
1.2 Research Title and Area Details

i.	Institutional Fellowship Title:	A women Centric approach to identify the factors governing the watershed integrity and multi-hazard susceptibility in selected districts of the Uttarakhand					
ii.	IHR State(s) in which Fellowship was implemented:	**Tehri Garhwal, Rudraprayag, Chamoli of Uttarakhand**					
iv.	Scale of Fellowship Operation	Local:	Yes	Regional:		Pan-Himalayan:	

iii.	Study Sites covered (*site/location maps to be attached*)	**Work done by HRA: Uttarakhand Districts: Tehri Garhwal, Rudraprayag, Chamoli**



Work done by HJRF: Takoli Gad Watershed, Tehri Garhwal, Uttarakhand



v.	Total Budget Outlay (Crore) :	Rs. 40,34,448/-

1.3 Details Himalayan Research /Project Associates/Fellows inducted

Type of Fellowship	Nos.	Work Duration	
		From	To
Research Associates	1	26th May, 2019	30th May, 2022
Jr. Research Fellows	1	27th May, 2019	30th May, 2022
Project Fellows	NA	-	-

2. Research Outcomes

2.1. Abstract (not more than 1000 words) (it should include background of the study, aim, objectives, methodology, approach, results, conclusion and recommendations based on the institutional fellowship proposal sanctioned under the NMHS).

HRA

Background: The Indian Himalayan region, which spans 12 states, accounts for 16% of India's total geographical area. The Himalayan Region (IHR) is considered vulnerable to natural disasters such as earthquakes, floods, landslides, and forest fires, among others. Rapid development is currently taking place in the Himalayas' environmentally sensitive region. The sensitive natural features of Uttarakhand such as fragile ecosystem, tectonic set-up and high precipitation are being made more precarious by the vested interests of people in real estate, haphazard tourism and plundering of natural resources as well as construction of mega hydro power projects. Like any mountainous region of the world, historically, Uttarakhand Himalayan region of India has suffered from frequent natural hazards in the forms of landslides, flash floods during monsoon and earthquakes. These incidences result in the loss of humans, agriculture lands, infrastructure, and further instability of mountain slopes and ecosystems. On 16 and 17 June 2013, the torrential downpour and subsequent flooding had wreaked havoc and swallowed vast swathes of Uttarakhand state. The cloudburst, heavy rainfall and subsequent landslides are the natural disasters but this disaster in the Alaknanda river basin of Uttarakhand is mainly attributed by masses as a man-made disaster that attracts special attention, worldwide. Therefore, it is essential to predict, prevent, and establish management plans for natural disasters.

Objectives/ Aim: Following are the research objectives:

- To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.
- Quantification of disproportionate opportunities of the women in disaster management.
- To identify the multi-hazard induced vulnerabilities by the local communities with special reference to women in the area.

Methodology(ies): The study is primarily based on publicly available remote sensing imagery and socioeconomic data collected through fieldwork and from key informants in the communities. House hold survey was performed in the areas that have multi-hazard susceptibility to identify the social vulnerability in the form of gender based parity.

Results:

- Kirtinagar block of Tehri Garhwal has highest multi hazard susceptibility followed by Bhilangna, Pratapnagar and Jakhnidhar constituting the eastern part of the district. Chamba block is found to have lowest susceptibility to natural hazards.
- In Rudraprayag district, the area having high to very high multi hazard susceptibility is concentrated near Ukhimath, Kedarnath and Agastmuni region. These regions have repeated history of natural disaster occurrence.
- Southern part of the Chamoli district is more prone to the multi hazard susceptibility compared to the northern part. Areas near Joshimath, Gopeshwar, Pokhari, Karanprayag, Tharali and Gairsain have high to very high multi hazard susceptibility.
- Out of the three studied districts, Chamoli has the highest multi hazard susceptibility followed by Rudraprayag and Tehri Garhwal.
- Household survey revealed that the men have higher risk awareness as compared to women in the study area. This can be linked to the level of education as women with higher education have more awareness towards natural hazard related risk as compared to the women who have low level of education.
- Women (79.1%) were found to be more sensitive towards the effects of natural hazards on the health than men (76.8%). Most women in the study area work in the agricultural fields but they also are housekeepers and child careers, which makes them more likely to be more sensitive to environmental threats.
- Based on the questionnaire survey FDGs and subsequent findings following factors were identified which defines the women's vulnerability in natural disasters:

- ➢ Socio-cultural
- ➢ Socio-economic
- ➢ Individual characteristics
- ➢ Legal/Institutional

Conclusion:

- This study offers a composite susceptibility assessment model for the study districts of Uttarakhand based on geospatial data and techniques in combination with social data. This was accomplished by assessing and combining risk from three natural hazards (landslides, floods, and forest fires) and subsequently developing a multi-hazard risk model that collectively considers the three types of hazards.
- Individual hazard zonation maps (landslides, forest fires, flash floods) and multi hazard susceptibility maps of the districts under study helped identifying the areas having high to very high susceptibility to one or more than one natural hazard. In Tehri Garhwal, Kirtinagar, Jakhnidhar, Bhilangana and Pratapnagar block are found to have high to very high multi-hazard susceptibility. Areas near Ukhimath, Agastmuni, Kedarnath in the Rudraprayag district has very high multi hazard susceptibility. Similarly, In Chamoli district, Joshimath, Karanprayag, Gopeshwar, Pokhari and Gairsain is having high to very high multi-hazard susceptibility.
- In present study gender differences were found in study area regarding a range of natural hazard preparedness indicators. Although there were some variables that indicated slight differences, larger magnitude and significant differences appeared to revolve around men's perceptions of being more prepared and being more active or willing to be involved in or led by community-level activities.
- Women generally reported being less confident, but perhaps had more realistic views about being prepared while also reporting more household- and family-level cares, concerns, and preparedness behaviors.
- Socio-cultural, socio-economic, individual characteristics and legal/institutional factors are found to be the important factors in defining the vulnerabilities of women in disaster management.
- This study can be replicated in other data scarce regions that are at risk to multiple hazards. Additionally, results from this approach can assist decision makers to better understand comprehensive risk and, consequently, to design more effective and spatially targeted policies to increase capacity and resilience.

- The results of this study can serve as the basis for targeting prioritization efforts, emergency response measures, channelizing funds, and raising environmental concern and policy interventions at district level for mitigating disaster vulnerability in the country

Recommendations:

- Learn more about and emphasize the role of women and men in emergency management planning and messaging;
- Engage in more in-depth research on gender roles, including more in-depth qualitative or mixed methods research that uses interviewing and/or focus group methodologies on gathering more in-depth information at ward level.
- Use a range of communication channels for increasing hazard knowledge and preparedness, including gender-related scenarios or case studies that appeal to people and promote empowerment and working cooperatively together within households and communities.
- Include natural hazard education in children's school curricula (e.g., education on gender empowerment and cooperation in the context of creating a current and future population that has resilience and risk management knowledge and skills) with the purpose to prepare for and solve problems linked to a range of risk scenarios in life such as natural hazards.

HJRF

Background:

The available natural resources are essential for the sustainable life which are becoming limited due to various factors like growing population, deforestation owing to growth of agricultural activities, small land holdings, lack of irrigation facilities, and urbanization which reduces the infiltration rates, and heavy soil erosion, landslides, declining soil fertility and frequent crop failures, resulting in scarcity of food, fodder and fuel, changes in land use land use cover. Hence, proper management and conservation of natural resources is critical. Watershed development has been conceived basically as a strategy for protecting the livelihoods of the people inhabiting the fragile ecosystems experiencing soil and moisture stress. Watershed management integrates decision-making processes to help assess the nature and status of the watershed, identify the watershed issues, define and re-evaluate short- and long-term objectives, actions and goals, assess benefits and costs and implement and evaluate actions. The watershed development programme in India has faced many challenges. The rural people of the Indian Himalayan region mainly depend on the natural resources their livelihood are greatly threatened by frequent climate change events. The rural livelihoods are likely to bear an uneven burden of the various effects of the climate change. In rural Himalayas, women are indeed the managers of natural resources. Participation of women is of paramount importance for the effective managers of community natural resources, and has learned to protect these resources in order to preserve them for future generations (managers of sustainability). Rural women actively participate in different activities i.e. soil-water conservation, crop production practices, practices for fodder, fuel and vegetable production and other practices like poultry, goat rearing, small scale industry etc. But women's contribution in sustainable agriculture system and watershed practices has been largely ignored. The impact of watershed development efforts on women is a key issue. Degradation of watersheds negatively affects the health, income, and work burden of women and girls. The use of a gender-sensitive approach to watershed management remains paramount ensuring that women's and men's unique needs, priorities, and knowledge are incorporated into management plans and policies.

Objectives/ Aim: Following are the research objectives:

- Characterization the watershed on the basis of available resources
- Assessment of physiochemical parameters of soil and water in the watershed.
- Watershed integrity index of the studied area.
- Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability.

Methodology(ies): Primarily, reconnaissance survey was conducted to assess the status of the Takoli Gad watershed in terms of physical, biological, economic and social factor. A literature survey was conducted in order to collect the existing information on sustainable watershed management involving local communities. SOI topographic sheets have been used for extraction of drainage network and delineation of the Takoli Gad watershed. Morphometric features such as linear, real and relief aspects have been calculated for watershed. Geo-rectified maps have been digitized in the GIS environment to produce thematic layer i.e. soil, geology-lithology, drainage network, and land use land cover. Multi-criteria decision analysis via analytical hierarchy process is the most popular and well known GIS based approach used for land and water management has been used for the characterization of the watershed. Soil and water samples were collected seasonally i.e. pre monsoon, monsoon and post monsoon and physico-chemical analysis was done in the laboratory as per standard methodology. Structured type questionnaire was prepared for defining the village socio economic profile. Frequent and detailed field surveys were conducted. Focused group interviews using common questionnaire with women and men were organized separately regarding the issues related to women particularly in terms of workload, decision making, access to information and earnings. Participatory Rural Appraisal (PRA) activities based on random sampling method were conducted in the Takoli Gad watershed for resource estimation as well as surveys related to analysis of developmental activities and policies implementation.

Results:

- The morphometric analysis of Takoli Gad watershed shows dendritic drainage pattern. Low Drainage density of the study area which indicates highly permeable subsoil, vegetative cover and very coarse drainage. Modest soil erosion is observed in the watershed hence conservation method can be proposed for the conservation of the natural resources available in the study region.
- The resource potential zone values were classified into five zones: excellent potential, good potential, moderate potential, low potential and very low potential zone. The results of this study shows that only 1.59 % (2.12 km^2) of the region exhibit excellent potential zone, 45.21 % (60.12 km^2) moderate potential zone, 25.61% (34.06 km^2) good potential zone, 26.41 % (35.13 km^2) poor potential zone and 1.18 %(1.57 km^2) very poor potential zone (Table 12).
- Water quality analysis is important for present conditions can be useful in the same ecological conditions at the future review to accessibility of safe drinking water.. The whole monitoring period was divided into three seasons, namely, pre monsoon, monsoon and post monsoon.

- From WQI, spring water can be ordered into five classes based on WQI values. According to the categorization out of total samples analyzed 28% spring samples comes under excellent water class, 72% samples has a place with good water class for Pre monsoon season, while 7 % of samples belongs to excellent water category where as 57 % samples were found of good water category and 36 % samples were found under poor water category for monsoon season and 64 % samples belongs to good water category and 36 % samples were found under poor water category for post monsoon season.
- ANOVA, ($p < 0.05$) seems to be significant for all the physicochemical parameters except electrical conductivity and bulk density (P value > 0.05). These parameter does not have any significant variations for the pre monsoon, monsoon and post monsoon season.
- Based on the field surveys and PRA studies, some parameters were identified which shows the contribution of women in various activities performed in the watershed. Various challenges faced by the local people in the watershed i.e. waters supply problem, wildlife problems, lack of quality education (non-availability of teachers in schools), lack of medical facilities, lack of hospitals (only aurveydic dispensaries) are present, lack of awareness about the policies, different schemes and programmes of the watershed management.
- The natural resources which are directly concerned with rural women are water for drinking and domestic purposes, fuel wood and fodder. Joint participation of women with men was lesser then the independent participation of women in all activities area.
- Overall, 65 % of the male members were solely responsible for all the decision made for their households. The jointness in decision making that was reported 33% which means that both men and women participated in decision making process equally but the minimum was that they were informed about the decisions.
- Women’s involvement in the planning and implementation of soil and water conservation and in managing newly created resources in the watershed is limited.

Conclusion:

- The present study illustrated the procedure of delineating and quantifying morphometric parameters in Takoli Gad watershed with the help of digital elevation model using

ArcGIS software. The morphometric study helps in understanding the watershed characteristics.

- The aim of this analysis is to investigate the potential application of AHP, GIS and RS approaches to map resource potential zones. Areas with low drainage density, high rainfall, lower slope and elevation also have a good to excellent resource potential zones.
- Samples of spring water were analyzed for pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, nitrate, calcium, magnesium, sodium, potassium, and total hardness. The outcomes were validated by comparing with WHO and BIS criteria for drinking water quality.
- The descriptive analysis of soil quality indicators suggests that the Takoli Gad watershed soils are suitable for cultivation. Pearson correlation and Principal Component Analysis reflected relations between some of the indicators analyzed, such as exchangeable cations and soluble cations and anions. Based on the above mention statistical analysis, electrical conductivity, bulk density, pH, soil organic matter, available phosphorous, available potassium and essential micronutrients were identified as the more representative indicators of the soil of different land use pattern of Takoli Gad watershed.
- Based on the field visits, surveys and PRA activities many issues were highlighted. Local people men and women both are unaware about the watershed policies and guidelines.
- There is need of training, skill development activities and workshops to be conducted in the watershed to enhance the sustainable livelihood status of the local people mainly included women that enhance water access for agriculture, water needs for household purposes, livestock etc., access to a steady flow of income to ensure food, fuel and financial security and participation in household decision-making and community affairs.
- The inclusion of women in decision-making processes is a pre-requisite to sustainable development in rural environments, especially for ensuring water security. Watershed intervention projects require gender transformative approaches across all social levels, from the household and community.

Recommendations:

- Need of joint efforts for better collaboration, bottom to up approach for successfully implementation of plans and policies in the region with the equal participation and contribution of the local people with the different stakeholders like government department, NGOs in the region.
- Based on the current quantitative research, there is an increasing need for more gender-focused mixed methods research to contextualize gender discrepancies in more depth and at a local scale.

2.2. Objective-wise Major Achievements

S. No.	Cumulative Objectives	Major achievements (in bullets points)
	HRA	
1.	To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.	• Understanding of the spatial distribution of the causative factors such as elevation, slope, aspect, rainfall, NDVI, LULC, Geology, TWI, roads, settlements, land surface temperature in the district under the study. • Developed landslide, forest fire and landslide susceptibility maps for Tehri Garhwal, Rudraprayag and Chamoli. • Developed multi hazard susceptibility maps for all three studied districts. • Developed landslides, forest fire and flash flood hazard inventories for the studied districts. • Identified areas that have high to very high multi hazard susceptibility. • Assessed the percentage area of the studied districts classified under very low to very high multi-hazard susceptibility.

2.	Quantification of disproportionate opportunities of the women in disaster management.	• Identified the competency of the women in disaster management. • Created awareness among local communities towards disaster management. • Identified the differential aspects that are limiting the roles of women in the study area.
3.	To identify the multi-hazard induced vulnerabilities by the local communities with special reference to women in the area.	• Identified various factors that are responsible for the vulnerabilities of the local women in the study area.
HJRF		

1.	Characterization the watershed on the basis of available resources	• Delineation of the Takoli Gad watershed • Morphometric analysis of the watershed i.e. linear aspect, areal aspect and relief aspect. The results of the analysis indicated that the morphometric features could be used to characterize a micro-watershed and determines its susceptibility to erosion as well as comprehend the basin hydrological behavior. The findings will be useful for soil and water erosion controls and watersheds management strategies in a sustainable manner. • Preparation of the various thematic maps that are factors identified for the estimation of the natural resources potential zones such as elevation, slope, rainfall, LULC, Geology, drainage density, and soil types in the watershed. The relative influence value and AHP weight calculated for resource potential zones. • A composite map of the Resource Potential Zones is developed for Takoli Gad watershed. The resource potential zones categorize into five different zones i.e. the excellent (1.59 %), good (25.61%), moderate (45.21 %), poor (26.41 %), and very poor (1.18 %) zones watershed. Hence, the resource potential zones aids in the accurate investigation of zones for agriculture, sustainable use of natural resources, and land management.

2.	Assessment of physiochemical parameters of soil and water in the watershed.	• Various water physicochemical parameters were analyzed for monsoon and post monsoon season i.e. pH, electrical conductivity, TDS, total hardness, calcium, magnesium, chloride, alkalinity, sodium, potassium. The outcomes were validated by comparing with WHO (2011) and BIS (2012) criteria for drinking water quality. As per the BIS and WHO standard value of drinking water, spring water samples are in the acceptable cap. • Water quality index (WQI) is calculated for the three different sampling season for pre monsoon, monsoon and post monsoon. The water quality index gives precise information on the degree of purity and pollution of water. Assessment and monitoring of spring water quality provides scientific data to support environmental and health decision making policies. The Water Quality Index (WQI) is a useful tool for informing the general public and policy makers about the water quality. • Various physicochemical parameters of soil were analyzed for monsoon and post monsoon season i.e. pH, electrical conductivity, bulk density, soil moisture, soil organic carbon, total nitrogen, available phosphorous, available potassium, available Sulphur and micronutrients (Copper, Manganese, iron and zinc) for different land use pattern i.e. forest land, agriculture land, settlement land and waste land. The values are validated by comparing soil health card, ICAR in which results varies by depth. Monitoring and assessment of soil quality are useful for determining the sustainability of soil management practices.

3.	Watershed integrity index of the studied area.	• "Watershed Integrity Index of the Takoli Gad watershed" will be the part of the PhD thesis. This objective will be compiled in the PhD thesis work.
4.	Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability.	• Identified the role of the women in watershed management. • Based on the field visits, surveys and PRA activities many issues were highlighted like lack of water supply system to various villages, poor health services, loss of agricultural yields due to destruction caused by wild animals, forest fire which leads to loss of fodder and fuel wood. Local people men and women both are unaware about the watershed policies and guidelines. The main source of occupation is agriculture and labor wages which they got under MNREGA scheme. • There is need of training, skill development activities and workshops to be conducted in the watershed to enhance the sustainable livelihood status of the local people mainly included women that enhance water access for agriculture, water needs for household purposes, livestock etc., access to a steady flow of income to ensure food, fuel and financial security and participation in household decision-making and community affairs. • The inclusion of women in decision-making processes is a pre-requisite to sustainable development in rural environments, especially for ensuring water security. Watershed intervention projects require gender transformative approaches across all social levels, from the household and community.

2.3. Outputs in terms of Quantifiable Deliverables*

HRA

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, and Reason thereof:
1.	Multi-hazard susceptibility mapping of the study region will make available essential information about the present and future disasters to people, engineers and planners to mitigate the construction problem caused by natural calamities.	Landslide, forest fire and flash flood susceptibility maps are integrated to produce multi-hazard susceptibility maps.	Resultant Multi-hazard susceptibility maps classified the study districts into five categories ranging from the zones that have very low susceptibility to the zones that are having high to vary high multi-hazard susceptibility. This information may be utilized as first-hand information by the engineers and planners for future construction activities in the studied district. The information disseminated from the multi-hazard susceptibility map could be integrated into the formulation of effective multi-hazard mitigation plan. As the level of mitigation measures could be decided on the basis of magnitude of the hazard risk. The information on the areas having high to very high multi-hazard	No

			susceptibility in the form of maps could be easily communicated to the local community which otherwise may be hard to understand by the local people. The multi-hazard susceptibility map identifies the critical areas where the disaster risk related awareness programmes could be conducted which will help the people to self-prepare themselves with the outcomes of the natural disasters.	
2.	Proper multi-hazard mitigation plan can be employed with the help of resultant multi-disaster susceptibility map.			
3.	Multi-hazard susceptibility map will help the locals in the study area to understand the current scenario of disaster risk so that they can self-prepare them to minimize the loss due to such natural calamities.			
4.	The overall livelihood of the locals in the area will be improved as the outcomes of the study will impart disaster risk related awareness among the people and henceforth facilitate the disaster risk reduction.			
5.	Evaluating the community impacts of multi-hazards shall deduce the information on the risk and problems	Household surveys, Focus group discussions,	The disproportionate opportunities of the women in disaster management are	No

	encountered by locals during and post disasters.	Key informant's interviews, Awareness program	studied through household survey on factors such as risk awareness, disaster preparedness and information & education. Women are found to have lower level of risk awareness as compared to men, however the sensitivity towards the health issues is found to be more in women. Men appeared to be more confident in managing an emergency situation, including the perception that they were better prepared to take action, including physical preparedness and response. Additionally, women had fewer opportunities to maintain a high level of social networking in the community, which may lead to them being less informed. Socio-cultural, socio-economic, individual characteristics and legal/institutional factors are found to be the important factors in defining the vulnerabilities of women in disaster management	

6.	Identified women vulnerabilities factors shall be useful for the regional disaster management authority to design an effective management plan so that the problems faced by women during and post disasters could be minimized.			
7.	Overall results of the deliverables will be published as scientific paper, report and will be presented in related conferences.	Book Chapter and presentation in National conference		

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

HJRF

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, and Reason thereof:
1.	The basic resources estimation of the study area will provide the base line data about the past and present scenario of the watershed.	Baseline data was generated for various parameters like rainfall, land use land cover, elevation, slope, drainage density, geology, soil types and morphometric parameters.	Delineation of watershed, Morphometric characterisation, & thematic maps, identification of resource potential zones via AHP approach using hydrology and ArcGIS tools	No
2.	Analysis of various water and soil parameters would predict the impact of anthropogenic activities on the watershed.	Seasonal analysis (pre monsoon, monsoon and post monsoon) of various physico-chemical parameters for perennial natural springs and soil type of different land use pattern i.e. agricultural, forest, settlement and waste land at	Water Quality Index was developed for different seasons (pre monsoon, monsoon and post monsoon) The descriptive analysis of soil quality indicators suggests that the Takoli Gad watershed soils are suitable for	No

		different depth.	cultivation. One-way analysis of variance (ANOVA, $p < 0.05$) is used to find an overall significant difference between all the studied sites and if the significant differences have been employed to identify the differences between the seasons i.e. pre monsoon, monsoon and post monsoon season	
3.	This would result in the preparation of a more comprehensive plan or development of a new index that are vital for managing and conserving the watershed sustainability.		"Watershed Integrity Index of the Takoli Gad watershed" will be the part of the PhD thesis. This objective will be compiled in the PhD thesis work.	
4.	Survey and PRA activities would result in the understanding of the gap areas and implementation of strong policies and governance.	Field surveys, Focus group interviews, Participatory Rural Appraisal, Awareness program	Based on the field visits, surveys and PRA activities many issues were highlighted like lack of water supply system to various villages, poor health services, loss of agricultural yields due to destruction caused by wild animals, forest fire which leads to loss of fodder and fuel wood. Local people men and women both are unaware about the watershed policies and guidelines.	No
5.	It would promote financial and food security and		There is need of training, skill	No

	improve health and living conditions.		development activities and workshops to be conducted in the watershed to enhance the sustainable livelihood status of the local people mainly included women that enhance water access for agriculture, water needs for household purposes, livestock etc., access to a steady flow of income to ensure food, fuel and financial security and participation in household decision-making and community affairs.	
6.	It would upgrade the women's input into decision making processes in families, institutions and village life.		The inclusion of women in decision-making processes is a pre-requisite to sustainable development in rural environments, especially for ensuring water security. Watershed intervention projects require gender transformative approaches across all social levels, from the household and community.	No
7.	Outcome of the research work will be the part of PhD thesis.	It will be the part of the PhD thesis work and publications		

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Enclosures
1.	New Methodology developed:	NA	NA
2.	New Models/ Process/ Strategy developed:	NA	NA
3.	New Species identified:	NA	NA
4.	New Database established:	NA	NA
5.	New Patent, if any:	NA	NA
	I. Filed (Indian/ International)		
	II. Granted (Indian/ International)		
	III. Technology Transfer (if any)		
6.	Others, if any:	NA	NA

3. Technological Intervention

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology	NA	NA
2.	Diffusion of High-end Technology in the region	NA	NA
3.	Induction of New Technology in the region	NA	NA
4.	Publication of Technological / Process Manuals	NA	NA
	Others (if any)	NA	NA

4. New Data Generated over the Baseline Data

<table>
<tr><th>S. No.</th><th>New Data Details</th><th>Existing Baseline</th><th>Additionality and Utilisation of New data (attach supplementary documents)</th></tr>
<tr><td>1.</td><td>Landslide susceptibility maps of the study districts through AHP using various causative factors such as rainfall, slope, aspect, NDVI, TWI, geology, soil, road proximity and drainage density.</td><td>The baseline information about the physical and geological factor is available but in the form of maps showing their spatial distribution in the study area</td><td rowspan="3">Data will be used for publication
Multi-hazard susceptibility mapping can be replicated for other districts of IHR which have the repeated history of one or more than one natural disaster
The resultant multi hazard map could be utilized by the decision makers, policy makers, engineers and the local community for as a first-hand information on the disaster risk in the region</td></tr>
<tr><td>2.</td><td>Forest fire susceptibility maps of the study districts through AHP using slope, aspect, drainage density, elevation, LULC, NDVI, LST, rainfall, road and settlements as causative factors.</td><td>Unknown</td></tr>
<tr><td>3.</td><td>Flash flood susceptibility maps of the study districts through AHP analysis using elevation, slope, rainfall, drainage density, soil, geology, geomorphology, LULC, TWI and NDVI.</td><td>Unknown</td></tr>
</table>

4.	Integrated maps depicting multi-hazard susceptibility of the study district has been prepared.	Unknown	
5.	Morphometric characterization of the Takoli gad watershed,	Little information is available	• Data will be part of the PhD thesis and used in publication • Chhillar, N. and Joshi, V. Application of remote sensing and GIS technique to identify resource potential zone for sustainable watershed: A case study of Takoli Gad watershed, Tehri Garhwal, Uttarakhand, India, published in Proc. SPIE 12262, Remote Sensing for Agriculture, Ecosystems, and Hydrology XXIV, 1226211(28 October 2022); doi: 10.1117/12.2638786 (Appendix 3 enclosed)
6.	Identification of the resource potential zones were computed through AHP approach using various thematic maps of elevation, slope, geology, soil, rainfall, land use land cover, and drainage density factors. A composite map of the Resource Potential Zones is developed for Takoli Gad watershed.	Unknown	

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

S. No.	Linkages /collaborations	Details	No. of Publications/ Events Held	Beneficiaries
1.	Sustainable Development Goals (SDGs)	NA	NA	NA
2.	Climate Change/INDC targets	NA	NA	NA
3.	International Commitments	NA	NA	NA
4.	National Policies	NA	NA	NA
5.	Others collaborations	NA	NA	NA

6. Financial Summary (Cumulative)*

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

7. Quantification of Overall Research Progress

S. No.	Parameters	Total (Numeric)	Attachments* with remarks
1.	IHR State(s) Covered:	*1*	*Uttarakhand*
2.	Fellowship Site/ LTEM Plots developed:	*NA*	*NA*
3.	New Methods/ Model Developed:	*NA*	*NA*
4.	New Database generated:	*NA*	*NA*
5.	Types of Database generated:	*NA*	*NA*
6.	No. of Species Collected:	*NA*	*NA*
7.	New Species identified:	*NA*	*NA*
8.	Scientific Manpower Developed (PhDs awarded/ JRFs/ SRFs/ RAs):	*1*	*Enrolled in PhD*
9.	No. of SC Himalayan Researchers benefited:	*NA*	*NA*
10.	No. of ST Himalayan Researchers benefited:	*NA*	*NA*
11.	No. of Women Himalayan Researchers empowered:	*NA*	*NA*
12.	No. of Knowledge Products developed:	*NA*	*NA*
13.	No. of Workshops participated:	*10*	*Appendix 2 enclosed*
14.	No. of Trainings participated:	*10*	
15.	Technical/ Training Manuals prepared:	*NA*	*NA*
	Others (if any):	*NA*	*NA*

***** Please attach the soft copies of supporting documents word files and data files in excel.

8. Knowledge Products and Publications*

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures **
		National	International		
1.	Journal Research Articles/ Special Issue (Peer-reviewed/ Google Scholar)	-	2	Appendix 1 enclosed	
2.	Book Chapter(s)/ Books:	2	-		
3.	Technical Reports/ Popular Articles	-	-		
4.	Training Manual (Skill Development/ Capacity Building)	-	-	-	-

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/ Enclosures ***
		National	International		
5.	Papers presented in Conferences/ Seminars	4	1	Appendix 1 enclosed	
6.	Policy Drafts (if any)	-	-	-	-
7.	Others (specify)	-	-	-	-

*Please append the list of KPs/ publications (with impact factor and URL link details) with due Acknowledgement to NMHS.

**Please provide supporting copies of the published documents.

9. Recommendation on Utility of Research Findings, Replicability and Exit Strategy

9.1 Utility of the Fellowship Findings

S. No.	*Research Questions Addressed*	*Succinct Answers (within 150–200 words)*
1.	Which areas are susceptible for multi-hazards in selected districts of Uttarakhand?	• Multi hazard susceptibility map of Tehri Garhwal shows that Kirti nagar block has high multi hazard susceptibility followed by Bhilangna, Pratap nagar and Jakhnidhar constituting the eastern part of the district. Chamba block is found to have lowest susceptibility to natural hazards. • Multi hazard susceptibility map of Rudraprayag shows that most of the area classified under high to very high multi hazard susceptibility is concentrated near Ukhimath, Kedarnath and Agastmuni region. These regions have repeated history of natural disaster occurrence. • Multi hazard susceptibility map of the

		Chamoli district demonstrate that the southern part of the district is more prone to the multi hazard susceptibility compared to the northern part. Areas near Joshimath, Gopeshwar, Pokhari, Karanprayag, Tharali and Gairsain have high to very high multi hazard susceptibility.
2.	What are the disasters induced vulnerabilities in women and what are the factors responsible for these vulnerabilities?	Disasters induce vulnerabilities in women: Gender-based violence: Women are at a higher risk of experiencing gender-based violence. In emergency situations, law enforcement and protection services may be unavailable, leaving women more vulnerable to exploitation and abuse. Lack of access to health services: Disasters can disrupt health services. Women may have difficulty in pre-natal care, and emergency obstetric care, which can have serious consequences for their health and wellbeing. Economic vulnerability: Women are often overrepresented in low-wage jobs and informal work, which are more likely to be affected by disasters. As a result, women may lose their jobs, experience wage cuts, or have to take on additional work to make ends meet, which can lead to economic insecurity and poverty. Displacement: Women are often disproportionately affected by displacement due to disasters, as they may have fewer resources and less mobility than men. Displacement can lead to a range of negative consequences,

		including separation from family members, loss of property and assets. Mental health: Disasters can have a significant impact on mental health, including increased rates of depression, anxiety, and post-traumatic stress disorder (PTSD). Women may be particularly vulnerable to these mental health challenges due to their caregiving responsibilities and social expectations. Overall, disasters can exacerbate existing vulnerabilities for women and create new ones, which can have serious and long-lasting consequences. It is important to take a gender-sensitive approach to disaster management and response to ensure that women's needs are taken into account and that they are not further marginalized or put at risk. Based on the questionnaire survey, FDGs and subsequent findings following factors were identified which defines the women's vulnerability in natural disasters: **Socio-cultural:** Socio-cultural factors such as Patriarchal culture, religious belief, household work load, household size could be considered important indicators for women's vulnerabilities. **Socio-economic:** Household income is identified as the determinant factor of socio-economic condition. It generally leads to lower level of engagement of women in decision making at house hold level. **Individual characteristics:** Characteristics of an individual such as their education level and

		self-interest are identified as important factors governing low level engagement of women in decision making limiting their role in disaster management. **Legal/ Institutional:** Interaction with focused group in the study area, political environment, policies and legislations and organizational cultures are recognized as the important indicators to know the roles and opportunities of women in disaster management.
3.	What is the reason for disproportionate opportunities for women during and post disaster?	There are several reasons why women may experience disproportionate opportunities during and after a disaster: Disasters can disrupt traditional gender roles: During a disaster, traditional gender roles may become less relevant as people focus on survival and recovery. Women may have skills that are in high demand during a disaster: Women are often trained in skills such as caregiving, nursing, and teaching, which can be critical during a disaster. Women may be needed to provide medical care, manage shelters, and assist with relief efforts. Women may be more likely to form social networks: Women are often responsible for maintaining social networks, which can be critical during a disaster. Women may be able to mobilize their networks to provide support and assistance to others in their community. Women may be more resilient: Women may

		have developed coping strategies that enable them to better cope with the stresses of a disaster. Women may be better at building and maintaining social support networks, which can be critical for resilience. Women may be more motivated to rebuild their communities: Women are often more invested in their communities and may be more motivated to rebuild after a disaster. Women may see disaster recovery as an opportunity to create a more equitable and sustainable future for their families and communities. Overall, it is important to recognize that women's increased opportunities during and after disasters may be the result of structural inequalities that limit women's opportunities in other contexts. It is important to work towards creating a more just and equitable society that provides equal opportunities for all.
4.	What are the factors that influence the sustainability of watershed management?	Morphometric characteristics including linear, areal and relief aspect, hydrology, topography, slope, aspect, elevation, climatic factors like rainfall, geology, soil types, land use land cover are the main factors that influence the sustainability of watershed management.
5.	What are the components of sustainable watershed management and how these can be integrated into a conceptual framework?	Sustainable watershed management is a holistic approach to manage natural resources and ecosystem services. It involves managing land, water and other resources in a way that promotes environmental sustainability, social well-being and economic prosperity. The key components are categorized into following

		classes: water quality management, sustainable land use, biodiversity conservation, social and economic management, climate change adaptation watershed planning and governance, integrated water resource management. To integrate these components into a conceptual framework, it is important to take holistic and collaborative approach. It should also be inclusive of all stakeholders from different sectors including participation of the local people and involvement of women in decision making process, local communities, non-government organizations, government agencies, to develop a shared vision and goals of the watershed. The framework should also include monitoring and evaluation mechanism to assess the progress. Also the framework should be flexible and adaptive to accommodate changing environment, social and economic conditions over time.
6.	What are the roles of women in maintaining the integrity of watershed?	Women plays an important role in maintaining the integrity of the watershed, as they are also responsible for managing the water resources and ensuring that the surrounding ecosystem are healthy and sustainable. Some of the key roles that women play in this process include: Water collection and management- Women are often responsible for collecting water and managing water resources in their communities. They may collect water from natural resources like rivers, streams or natural spring. Women also play a key role in managing the irrigation

		systems Farming and land management- Women are involved in farming and land management which can have a significant impact on the health of the watersheds. Women use sustainable farming practices that help to preserve the soil quality and reduce erosion and promotes healthy watersheds. Awareness and advocacy- Women can play a key role in raising awareness about environmental issues and advocating for policies that protect healthy watersheds. They may also work with local communities, non-governmental agencies, government officials to create awareness about the importance of watershed conservation. Conservation and restoration: Women may be involved in conservation and restoration efforts that help to restore damage watershed. they may plant tree and other vegetation, implement other measures that help to improve water quality and protect wildlife habitats. Overall, women play critical role in maintaining the integrity of the watersheds, and their contributions are essential to ensuring water resources are managed in a sustainable and equitable manner.
7.	How can sustainable watershed management be implemented including the role of people participation?	Sustainable watershed management is crucial for the protection and conservation of water resources. It involves managing the watershed area in a way that balances environmental, social and economic needs to ensure the long

		term sustainability of the ecosystem. People participation is an essential aspect of sustainable watershed management because it involves the active involvement of the local communities, stake holders and others in the decision making and implementation process. Here are some ways to implement sustainable watershed management with the people participation: Involvement of the local people: Engaging local people in the decision making, planning and implementation process which enhances the sense of responsibility and ownership. Encourage them to participate in monitoring and data collection, identifying and reporting environmental problems, and implementing conservation measures. This can be achieved through communities meeting, workshops and training programs. Promote water conservation practices: Encourage local people to adopt water conservation practices such as rain water harvesting, efficient water use that reduces the demand for water and minimize the impact of human activities on watershed. Implement soil and water conservation practices: Soil erosion is the significant issue in the watershed. Practices such as terrace farming, contour farming can reduce the soil erosion problem and promote soil health. Use Sustainable Land Use Practices: Land use practices, such as agriculture, forestry, and

		urban development, can have significant impacts on watersheds. Encourage the use of sustainable land use practices, such as conservation tillage, agroforestry, and low-impact development techniques, that minimize negative impacts on the environment. Monitor and Evaluate Progress: Regular monitoring and evaluation of the watershed management plan are necessary to ensure that goals are being achieved, and the plan is effective. Monitoring can involve the collection of data on water quality, biodiversity, and other environmental indicators. Evaluation can involve assessing the effectiveness of management strategies and identifying areas for improvement. Promote Public Awareness: Raise awareness about the importance of watersheds and the need for sustainable watershed management. This can include organizing community outreach and education programs, developing educational materials, and promoting eco-tourism activities that highlight the ecological and economic benefits of healthy watersheds. Overall, the implementation of the sustainable watershed management with people requires collaborative efforts among stakeholders. By involving local people in decision making, promoting sustainable practices and strengthening governance and regulatory framework, the long-term sustainability of the

		watershed can be ensured.

9.2 Recommendations on Replicability and Exit Strategy:

Particulars	Recommendations
Replicability of Fellowship, if any	• Multi-hazard susceptibility mapping can be replicated for other districts of IHR which have the repeated history of one or more than one natural disaster • Hazard zonation maps can be developed at ward level wherein the wards can be ranked high to low hazard susceptible areas. • Hazard inventory at ward level could be developed having details on the type/scale of the hazard, date and impacts. • In depth research on gender roles including more in depth qualitative or quantitative methods research can be carried out at ward level to gather micro level information on gender roles in disaster and watershed management. • Survey results provide ways of capacity building in the area of disaster and watershed management. Stakeholders and their roles and responsibilities could be mapped and trainings could be provided to the local communities to cope up with the challenges identified in disaster and watershed management. • Awareness programs could be conducted for the local communities and visitors about various issues pertaining to the sensitivity of the Himalayan environment. • Gaps in the current disaster management plans could be identified at the district level. • Extensive research on the impact of the anthropogenic activities on natural disaster frequency and probability.

Exit Strategy:	*Please describe the Exit Strategy of the fellowship, self-sustaining and benefitting the stakeholders and target communities*: This project was a research and awareness building project. Exit Strategy is not applicable.

(**NMHS FELLOWSHIP COORDINATOR**)

(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)

(Signed and Stamped)

Place: ………………..
Date: …../……/……..

PART B: COMPREHENSIVE REPORT (including all sanctioned positions of Researchers)

Based on the Fellowship Proposal submitted/approved at the time of sanction, the co-ordinating Principal Investigator shall submit a comprehensive report including report of all individual researchers.

The comprehensive report shall include an **Executive Summary** and it should have separate chapters on (1) **Introduction** (2) **Methodologies, Strategy and Approach** (3) **Key Findings and Results** (4) **Overall Achievements** (5) **Impacts of Fellowship in IHR** (6) **Exit Strategy and Sustainability** (7) **References/ Bibliography** and (8) **Acknowledgements** (It should have a mention of financial grant from the NMHS, MoEF&CC).

Further, description of Technical Activities, List of Trainings/ Workshops/ Seminars with details of trained resources, list of New Products developed under the fellowship, Manual of Standard Operating Procedures (SOPs) developed, Technology developed/Transferred etc should be enclosed as Appendix.

Report (hard copy) should be submitted to:

Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies (NMHS)
G.B. Pant National Institute of Himalayan Environment (GBP NIHE)
Kosi-Katarmal, Almora 263643, Uttarakhand

Report (soft copy) should be submitted at:

E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; gupta.dharmendra@gov.in

COMPREHENSIVE REPORT BY HRA

Executive Summary

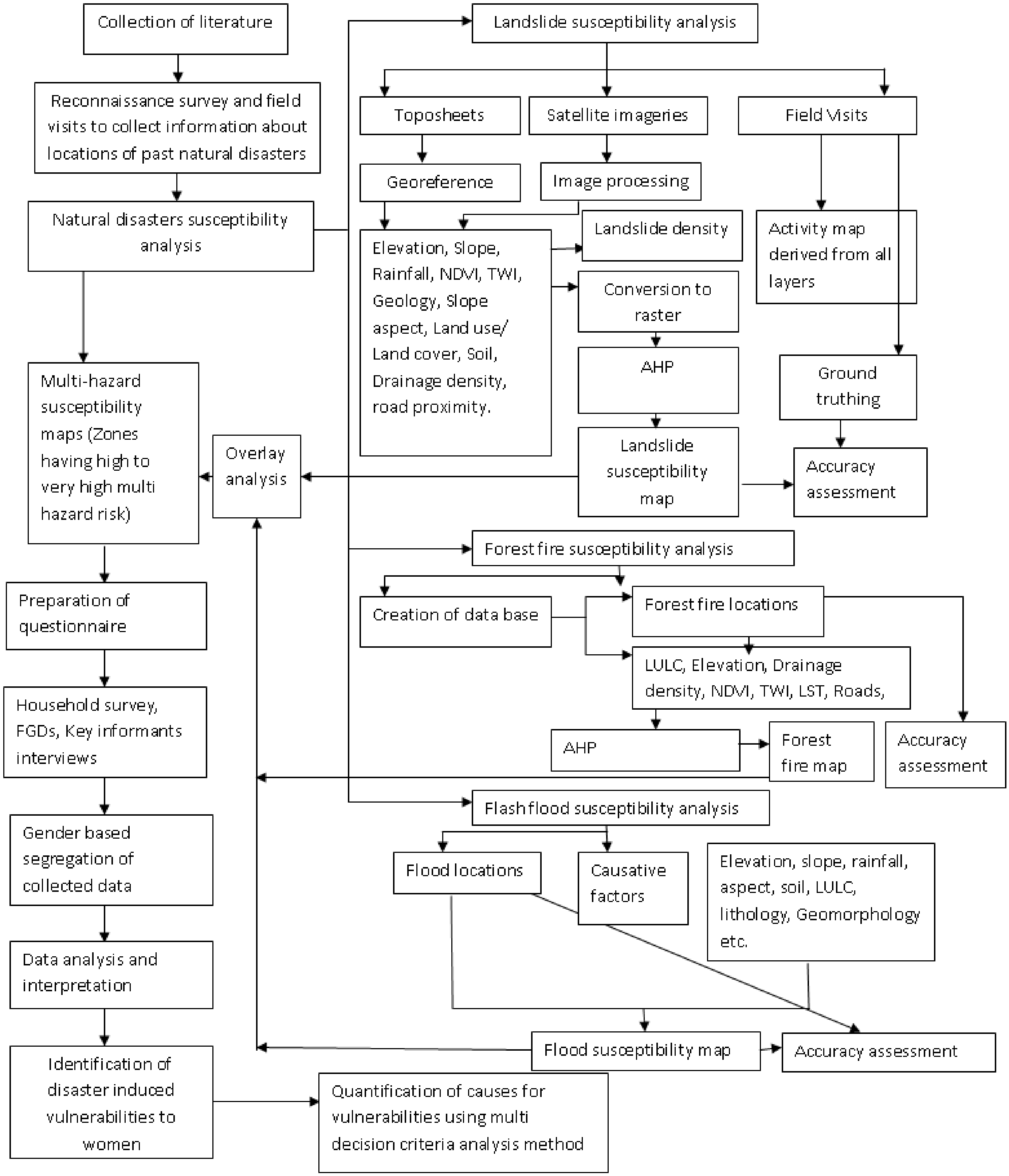
The frequency and damage caused by natural disasters is increasing worldwide Concurrently, the worsening trend of climate change greatly impacts the frequency and hazard level of natural disasters on a global scale (Kappes et al. 2012; Haque et al. 2019). India was ranked as the 14th most vulnerable nation in the world as a result of extreme weather-related incidents. In 2017, India lost approximately 2,736 lives due to disasters, with an economic loss of approximately $13,789 million, ranking fourth in the world (GREMANWATCH, 2019). India is one of the most disaster-prone countries in the world due to its geo-climatic conditions and high socioeconomic vulnerability. India is vulnerable to a variety of natural disasters, including earthquakes, floods, cyclones, landslides, and tsunamis. India suffered from nearly 431 natural disasters between 1980 and 2010, which resulted in 1.4 lakh fatalities, 15 crore affected, and a loss of US$48.06 billion in economic output (EM-DAT, 2019). Years of development work and infrastructure are constantly being destroyed and eroded as a result of growing urbanization and an increase in the frequency of small and large-scale disasters in urban areas (Sanderson, 2000).

The Indian Himalayan region, which spans 12 states, accounts for 16% of India's total geographical area. The Himalayan Region (IHR) is considered vulnerable to natural disasters such as earthquakes, floods, landslides, and forest fires, among others. On average, 76 disasters strike IHR each year, killing 36,000 people and affecting 178 million people. Between 2009 and 2018, the Himalayan region experienced nearly 127 landslides (Khadka, 2021). Rapid development is currently taking place in the Himalayas' environmentally sensitive region. Environmental degradation has resulted from hasty adaptations to such rapid changes (Anbalagan, 1993). If not handled carefully, increasing levels of urbanization will be extremely harmful to the climate and people of the Himalayas (Walker, 2011). Uttarakhand state of India is one such centers of pilgrim activities in the Himalaya, which is visited by millions of pilgrims, as it has four major Hindu and one Sikh shrines – the Badrinath, Kedarnath, Gangotri, Yamunotri and Hemkund. In order to fulfill the need of such a huge number of pilgrims an intricate network of roads, hotels, lodges and related support systems has built into the remote mountainous areas of the Himalaya. The sensitive natural features of Uttarakhand such as fragile ecosystem, tectonic set-up and high precipitation are being made more precarious by the vested interests of people in real estate, haphazard tourism and plundering of natural resources as well as construction of mega hydro power projects. Like any mountainous region of the world, historically, Uttarakhand Himalayan region of India has suffered from frequent natural hazards in the forms of landslides, flash floods during monsoon and earthquakes. These incidences result in the loss of humans, agriculture lands, infrastructure, and further instability of mountain slopes and ecosystems. On 16 and 17 June 2013, the torrential downpour and subsequent flooding had wreaked havoc and swallowed vast swathes of Uttarakhand state. The cloudburst, heavy rainfall and subsequent landslides are the natural disasters but this disaster in the Alaknanda river basin of Uttarakhand is mainly attributed by masses as a man-made disaster that attracts special attention, worldwide. Therefore, it is essential to predict, prevent, and establish management plans for natural disasters. One of the primary methods for predicting and managing natural hazards is the construction of hazard susceptibility mapping data (Yousefi et al. 2020). By generating geospatial information, susceptibility maps can provide important information for natural hazard prediction, prevention, and management.

In addition to analyzing the hazard susceptibility profile of the region, it is also essential to look into the social vulnerabilities arising from natural disasters. It is a well-known fact that disasters don't impact both genders equality. Women are especially hard-hit by the social impacts of environmental disasters. Existing inequalities are the root cause of women's disaster vulnerability. Global forces and social changes placing more people at greater risk of disaster also disproportionately impact women. Highly vulnerable women have specific needs and interests before, during, and after disasters. Gender shapes capacity as well as vulnerability. Women are active and resourceful disaster responders but most often are regarded as helpless victims.

In this background the present study aimed at developing individual as well as integrated hazard susceptibility map of the three disaster prone districts of the Uttarakhand i.e. Tehri Garhwal, Rudraprayag and Chamoli. Landslides, forest fire and flash floods being the most frequent natural disasters in the selected districts are considered for the susceptibility mapping. Further, the individual maps are used to generate the integrated multi hazard maps of the study districts. Household surveys, focused group discussions and key informant's interviews are conducted in the regions that have high to very high multi hazard susceptibility to find out the factors that are contributing the vulnerabilities to the women in the study area.

The methodology followed during the present study is described in the flow chart:



Outcomes: The broad outcomes of the Project have been enlisted as per the objectives:

	Objectives	Outcomes
1.	To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.	• Understanding of the spatial distribution of the causative factors such as elevation, slope, aspect, rainfall, NDVI, LULC, Geology, TWI, roads, settlements, land surface temperature in the district under the study. • Developed landslide, forest fire and landslide susceptibility maps for Tehri Garhwal, Rudraprayag and Chamoli. • Developed multi hazard susceptibility maps for all three studied districts. • Developed landslides, forest fire and flash flood hazard inventories for the studied districts. • Identified areas that have high to very high multi hazard susceptibility. • Assessed the percentage area of the studied districts classified under very low to very high multi-hazard susceptibility.
2.	Quantification of disproportionate opportunities of the women in disaster management.	• Identified the competency of the women in disaster management. • Created awareness among local communities towards disaster management. • Identified the differential aspects that are limiting the roles of women in the study area.
3.	To identify the multi-hazard induced vulnerabilities by the local communities	• Identified various factors that are responsible for the vulnerabilities of the local women in the study area.

	with special reference to women in the area.	

Project outputs:

The output of the project has been listed in the following table:

S. No.	Tehri Garhwal	Rudraprayag	Chamoli
1.	**Hazard inventory maps:** Landslide inventory Forest fire inventory Flashflood inventory	**Hazard inventory maps:** Landslide inventory Forest fire inventory Flashflood inventory	**Hazard inventory maps:** Landslide inventory Forest fire inventory Flashflood inventory
2.	**Causative factors maps:** Elevation map Rainfall map Slope map Aspect map NDVI map TWI map Soil map Drainage density map Geology map Lithology map	**Causative factors maps:** Elevation map Rainfall map Slope map Aspect map NDVI map TWI map Soil map Drainage density map Geology map Lithology map	**Causative factors maps:** Elevation map Rainfall map Slope map Aspect map NDVI map TWI map Soil map Drainage density map Geology map Lithology map

	Geomorphology map LULC map Road map Settlement buffer map Land surface temperature map	Geomorphology map LULC map Road map Settlement buffer map Land surface temperature map	Geomorphology map LULC map Road map Settlement buffer map Land surface temperature map
3.	**Individual hazard susceptibility maps** Landslide susceptibility map Forest fire susceptibility map Flash flood susceptibility map	**Individual hazard susceptibility maps** Landslide susceptibility map Forest fire susceptibility map Flash flood susceptibility map	**Individual hazard susceptibility maps** Landslide susceptibility map Forest fire susceptibility map Flash flood susceptibility map
4.	Integrated multi hazard susceptibility map	Integrated multi hazard susceptibility map	Integrated multi hazard susceptibility map
5.	Factors limiting the roles of local women in disaster preparedness and management	Factors limiting the roles of local women in disaster preparedness and management	Factors limiting the roles of local women in disaster preparedness and management

1. Introduction

1.1 Background of the project:

Extreme environmental events are the topic of major concern all over the globe. During the last few decades, there is an increase in number of people affected by the natural calamities – cyclones, landslides, earthquake, floods, droughts, forest fire etc. The Himalayan system is prone to the natural disasters because of its extremely dynamic system. In the current scenario, the Uttarakhand is repeatedly devastated by both geological and hydrometereological disasters (Pandey and Mishra, 2015). Uttarkashi, Pithoragarh, Chamoli, Pauri and Rudraprayag districts of Uttarakhand Himalaya have witnessed most terrible form of disasters in recent past. In 2012, unusually heavy rainfall was received in Uttarkashi and Rudraprayag districts of Uttarakhand which affected around 13,137 people inhabiting 236 villages and a number of towns. 106 persons were reported to be killed by that disastrous event (Khanduri et al., 2011). In the year 2013, the Uttarakhand has been severely affected by floods and landslides. Chamoli Rudraprayag and Pauri districts have a history of repeated natural disasters due to its geological, climatic and structural conditions (Khanduri, 2018). These districts have experienced repeated landslides and flash floods in past years. Numerous times, these natural disasters have caused immense loss to the human lives and property. Apart from these disasters, forest fire is also one of the major disasters in the forest of Tehri district affecting the life of inhabitants. Frequent forest fires have been reported in Uttarakhand and the most affected areas include Almora, Chamoli, Pithoragarh and Tehri districts.

The natural hazards affect the local communities at a very large extent. Preparation of disaster inventory and susceptibility maps is the most important step in the development of disaster management plan. These maps provide substantial information to support decision for land use planning and development. Furthermore, effective use of these maps can significantly lessen the damage potential and cost impacts of natural disasters. Apart from identifying the vulnerability of the region for natural calamities, it is also essential to analyze its corresponding impacts on community. As the resultant information can facilitate the community leaders to quantify the need of locals based for external assistance. Moreover, the information deduced from the impact study can be used to recognize the section of the community that have been affected disproportionally (for eg. Low income groups, minorities, females etc).

Uttarakhand being the hotspot of natural disasters is studied by various researchers for its vulnerability towards natural disasters. But, the integrated approach of assessing the region for their susceptibility to disasters and quantifying the impacts of natural calamities has not been attempted. Therefore, the present study is intended to develop a spatial model in order to identify the regions having high susceptibility of natural disasters along with the contributing factors through the integration of geospatial technologies. Simultaneously, the study involves the assessment of impacts of the disasters on the local community in terms of their socio demographic, economic and health vulnerabilities. The study areas selected for the proposed work are Chamoli, Tehri and Rudraprayag districts of Uttarakhand.

1.2 Overview of the major issues addressed

The frequency and damage caused by natural disasters is increasing worldwide (Munich et al. 2014). Concurrently, the worsening trend of climate change greatly impacts the frequency and hazard level of natural disasters on a global scale Therefore, it is essential to predict, prevent, and establish management plans for natural disasters One of the primary methods for predicting and managing natural hazards is the construction of hazard susceptibility mapping data By generating geospatial information, susceptibility maps can provide important information for natural hazard prediction, prevention, and management. Many researchers around the world focus on single hazards, such as landslides (Wang et al., 2020a, Habumugisha et al., 2022, Youssef et al., 2022a), floods (Hosseini et al., 2021, Rafiei-Sardooi et al., 2021), debris flows (Marra et al., 2017, Abuzied and Pradhan, 2021), forest fires (Abedi Gheshlaghi et al., 2021, Feizizadeh et al., 2022), and glacier avalanches (Choubin et al., 2019, Yariyan et al., 2022). However, many locations are susceptible to multiple hazards, which may occur simultaneously. Mitigating one hazard may exacerbate the frequency, duration, distribution, or intensity of another hazard, especially in the mountainous regions. Therefore, it is important to assess the multi hazard susceptibility of the regions which have the history of repeated one or more type of natural disasters. Present study addresses the important issue of disaster management in the Uttarakhand state which has been the hotspot of natural disasters in recent past. The project will identify the zones in the study region which are at highest risk of multiple disaster occurrence. Since, the natural calamities destroy the community at a large extent therefore it is essential to identify the barriers and factors which are responsible for inducing vulnerabilities in the local community.

Gender disparities exert powerful differences within societies worldwide, even in the field of disasters. Women and men are not merely at risk because of their location in time and place but because of a complex mix of influential factors that include “differentiated roles and responsibilities, skills and capabilities, vulnerabilities, social relations, institutional structures, and long-standing traditions and attitudes”. The assessment of gender differences at all levels of the disaster cycle has historically been less than satisfactory. The social research on disasters has often been approached from a mostly gender-blind perspective, mindful of some basic findings reported in the literature for years (e.g., women are more at risk for psychosocial reactions. This social–cognitive bias can influence disaster management actions in place, affecting both physical actions and psychosocial preparedness and response increased interest in gender inclusion in the disaster context occurred during the International Decade for Natural Disaster Reduction (1990–1999); however, gender-specific guidelines were missing. In 2000, the special session of the UN General Assembly, “Gender equality, development and peace for the twenty-first century” highlighted the inefficiencies and inadequacies of existing approaches in responding to disasters Thus, the need for explicitly incorporating considerations on gender into disaster prevention, mitigation, and recovery strategies has been increasingly emphasized. Consequently, the present study estimated the variation in gender vulnerability to recognize who will be at larger risk in the event of a disaster and assess the differential impacts among groups.

1.3 Project objectives and Target Deliverables (as per the NMHS sanction order)

Position	Study Area	Proposed Objectives	Deliverables
HRA01	Uttarakhand	• To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks. • Quantification of disproportionate opportunities of women in watershed and disaster management.	• Multi-hazard susceptibility mapping of the study region will make available essential information about the present and future disasters to people, engineers and planners to mitigate the construction problem caused by natural calamities.

Position	Study Area	Proposed Objectives	Deliverables
		• To identify the multi-hazard induced vulnerabilities and constraints faced by the local communities with special reference to women in the area	• Proper multi-hazard mitigation plan can be employed with the help of resultant multi-disaster susceptibility map. • Multi-hazard susceptibility map will help the locals in the study area to understand the current scenario of disaster risk so that they can self-prepare them to minimize the loss due to such natural calamities. • The overall livelihood of the locals in the area will be improved as the outcomes of the study will impart disaster risk related awareness among the people and henceforth facilitate the disaster risk reduction. • Evaluating the community impacts of multi-hazards shall deduce the information on the risk and problems encountered by locals during and post disasters. • Identified women vulnerabilities factors shall be useful for the regional disaster management authority to design an effective management plan so that the problems faced by women during and post disasters could be minimized.

Position	Study Area	Proposed Objectives	Deliverables
			• Overall results of the deliverables will be published as scientific paper, report and will be presented in related conferences.

METHODOLOGIES, STRATEGY AND APPROACH

2.1 Methodologies used for the study

(i) Study area

- The study area comprises three hazard prone districts of Uttarakhand i.e. Chamoli, Rudraprayag and Tehri (Figure1). The geographical extent of the study area extends from 31o 4′40.8″ N to 29o 55′4.8″ N and 77o 55′33.6″ E to 80o 5′49.2″ E in Garhwal Himalayan region of India. The study area lies in Uttarakhand district which is highly vulnerable to geological and climate mediated risks. There is a history of reoccurring disasters in the Uttrakhand since 1803. Flash flood of the year 2013 was responsible for the extensive loss of human lives and infrastructure in Kedarnath and other districts along the Mandakini and Alaknanda rivers (Maikhuri et al., 2017). According to the report of Doyle et al. (2017), Ghansali, Tharali, Pokhari, Ukhimath, Rudraprayag, Devprayag, Kalsi, Kapkot, Jakholi, Dunda, Laksar sub district has very high biophysical and social vulnerabilities to natural disasters. Majority of these sub-districts falls under Tehri Garhwal, Rudraprayag and Chamoli district of Uttarakhand. The study area is therefore chosen in perspective of the areas which not only have biophysical vulnerabilities to natural disaster but also have elevated social vulnerabilities. Location map of the study area is given in Fig.1

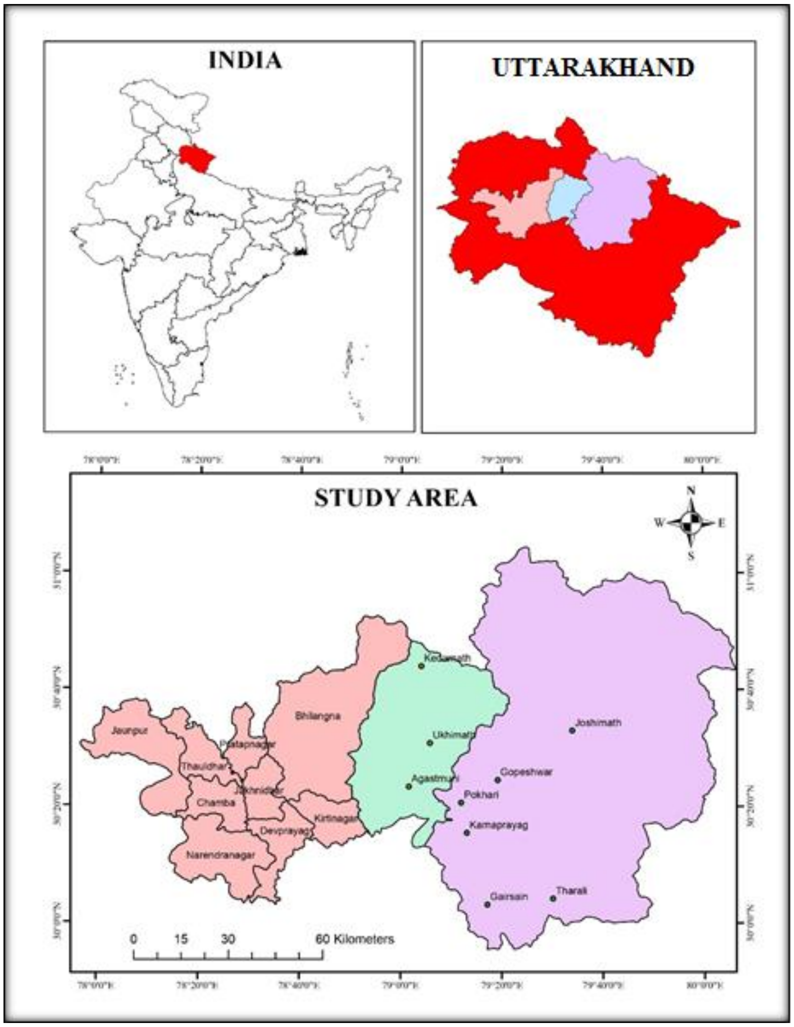


Figure 1: Map of the Study area

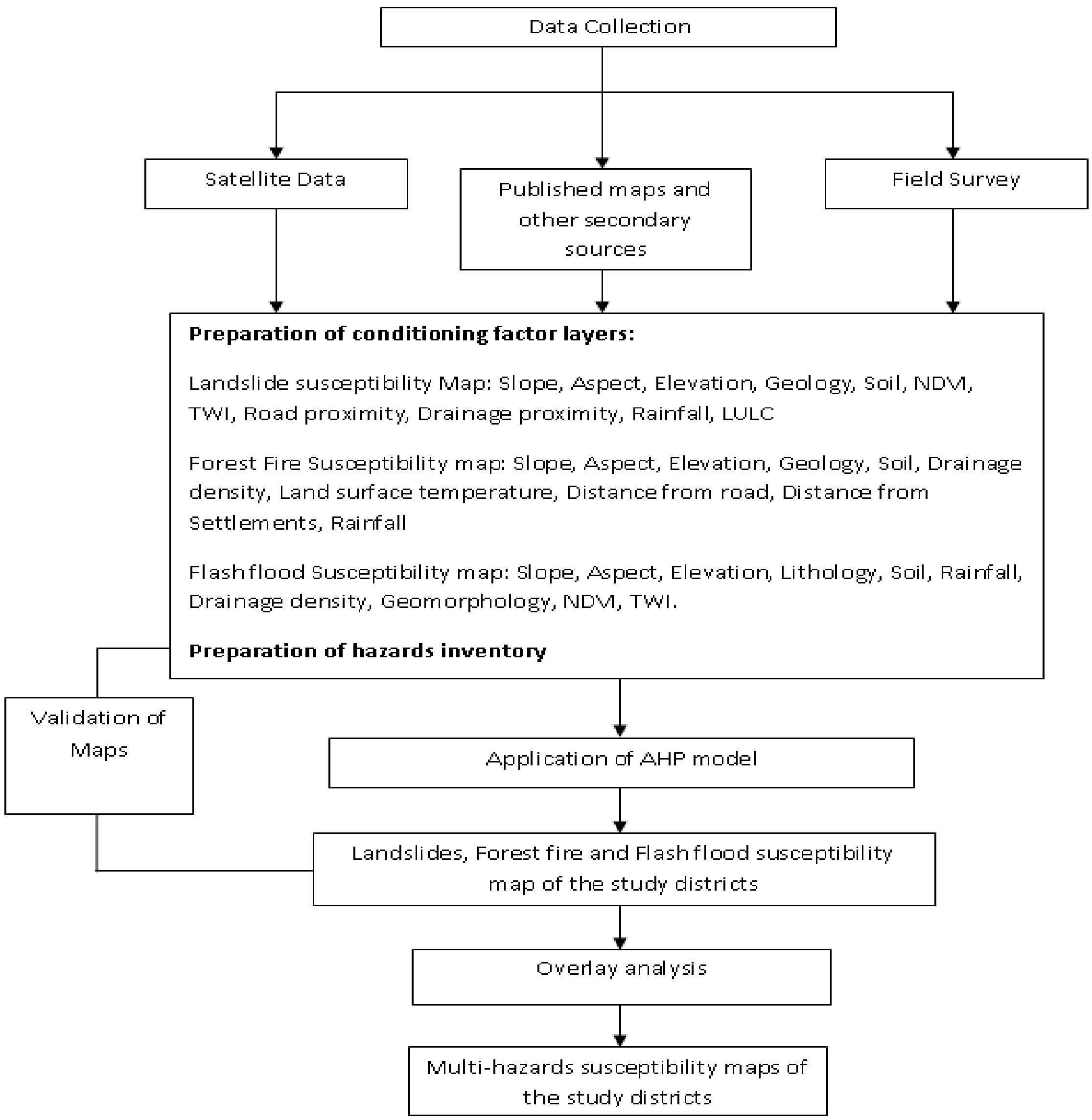
(ii) Reconnaissance survey: First of all a reconnaissance survey was conducted in Tehri Garhwal, Rudraprayag and Chamoli district to identify the sites of past landslides, flash floods and forest fires and to assess the status of the district in terms of their physical, social and economic characteristics.

(iii) Review of literature: A literature survey was conducted in order to collect the existing information on past natural disasters in the study area and about the challenges faced by women in disaster management in the area. Information from published journals, books, reports as well as past and present records from government were collected.

For each objective, a number of activities were planned using standard methodologies

Objective 1: To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.

Multi-hazard Susceptibility analysis: The Flow chart of overall adopted methodology is given in figure 2. The first step in multi-hazard mapping is generating geospatial database which includes hazard inventories and thematic layers of triggering/predicting factors.



Geospatial database creation

In present study, data from various sources such as high resolution satellite image, extensive field survey, published maps and literature review is procured.

Hazard inventory preparation

The hazard inventory map is an essential step in evaluating hazard susceptibility, hazard and risk (Guzzetti et al. 2012). Van Westen (2000) suggested that the different data such as field investigations, historical hazard events and satellite image analysis can be used to prepare the hazard inventory. Locations of past landslides were recorded through GPS during extensive field survey during February 2021 to November 2021. The recorded landslides locations were placed over high resolution satellite imagery of the region and area of the landslide was demarcated using ArcGIS software. The locations of all landslides in the area could not be recorded through field survey owing to the high ruggedness and inaccessibility to the region. However, in such case, the landslides locations were inferred through satellite images. Historical landslide events were also procured from Bhukosh landslide inventory by Geological survey of India. Landslide inventory map of the Tehri Garhwal, Rudraprayag and Chamoli is presented in figure 2a, 2b and 2c respectively. Locations of past forest fire events was obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) for the study districts and are used to prepare the forest fire inventory maps. Forest fire inventory of Tehri, Rudraprayag and Chamoli districts are presented in figure 3a, 3b, 3c. Flash flood inventory of Tehri, Rudraprayag and Chamoli districts are prepared by extracting flash flood points from local newspapers, published research papers and reports. Flash flood inventory map of Tehri Garhwal, Rudraprayag and Chamoli districts are presented in figure 4a, 4b, 4c.

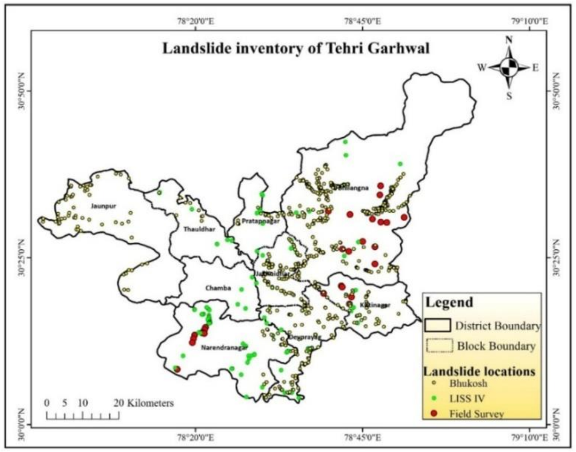


Figure 2a: Landslide inventory map of Tehri Garhwal

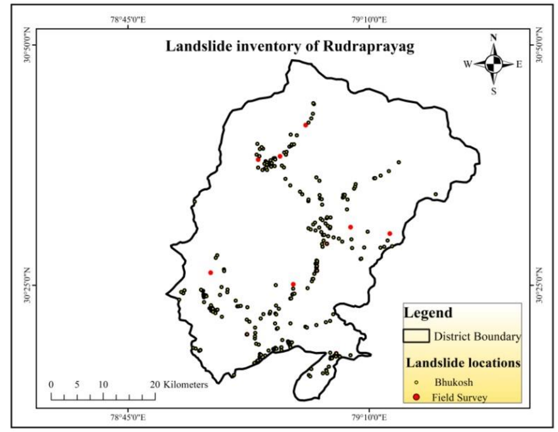


Figure 2b: Landslide inventory map of Rudraprayag

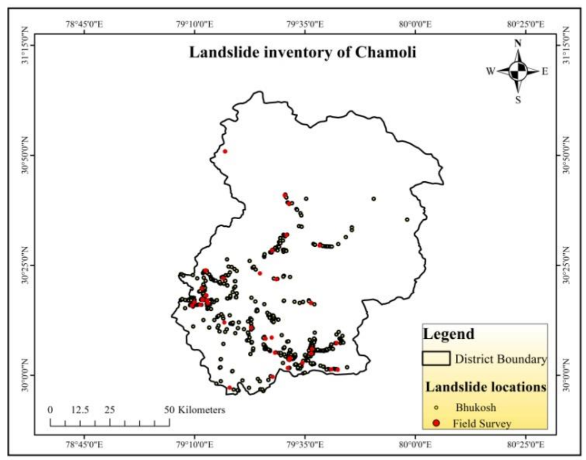


Figure 2c: Landslide inventory map of Chamoli

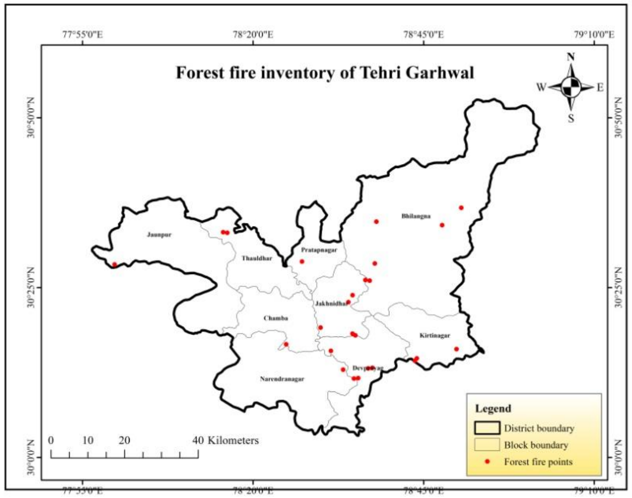


Figure 3a: Forest fire inventory map of Tehri Garhwal

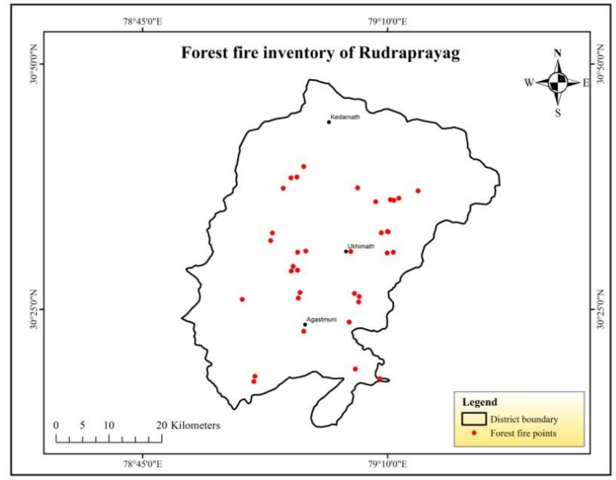


Figure 3b: Forest fire inventory map of Rudraprayag

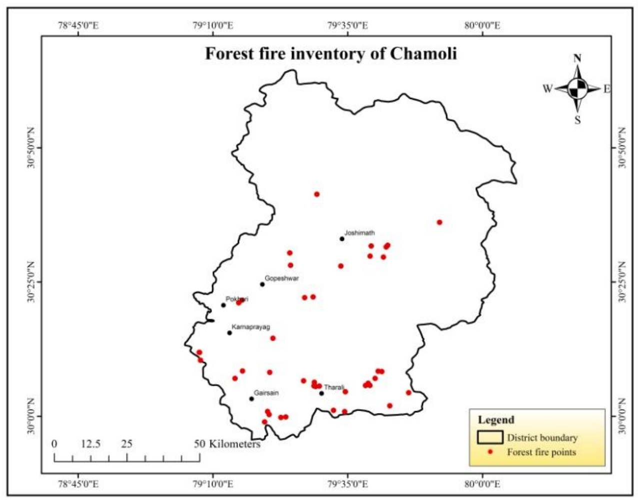


Figure 3c: Forest fire inventory map of Rudraprayag

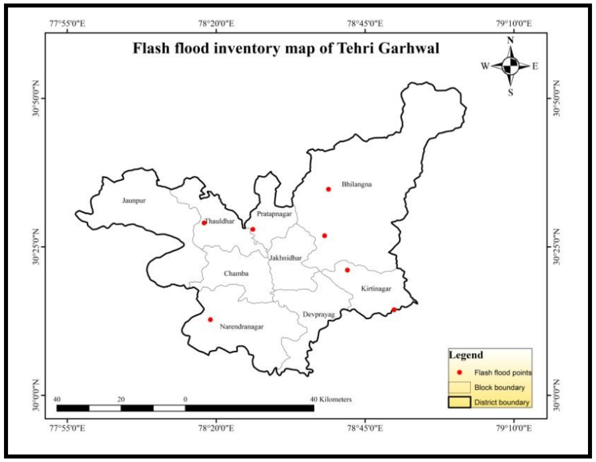


Figure 4a: Flash flood inventory map of Tehri Garhwal

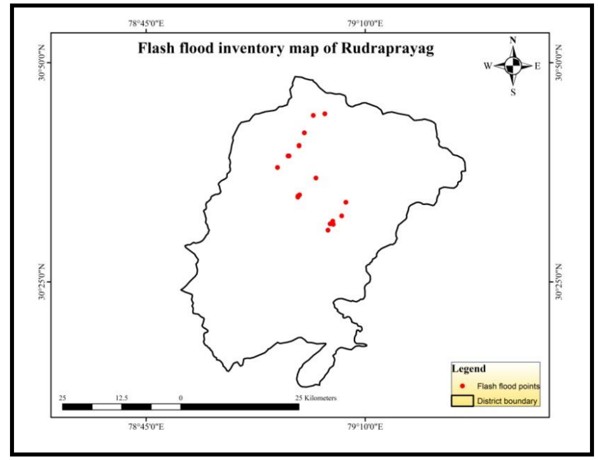


Figure 4b: Flash flood inventory map of Rudraprayag

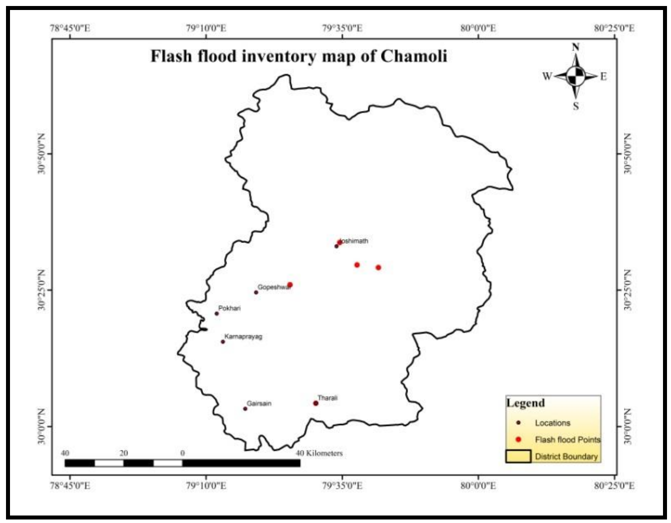


Figure 4c: Flash flood inventory map of Chamoli

Preparation of thematic layers of selected parameters

The average annual rainfall data of last five years 2017 to 2021 have been collected from Indian Meteorological Department. The thematic layer of rainfall for Tehri Garhwal (figure 5a), Rudraprayag (figure 5b) and Chamoli (figure 5c) has been prepared with the help of Inverse Distance Weighted (IDW) tool in ArcGIS, based on average annual rainfall data of last five years. The slope map of the study area has been prepared from SRTM DEM with the help of spatial analyst tool of ArcGIS software (figure 6a-6c). In case of elevation and aspect, these data layers have been prepared from SRTM DEM with the help of spatial analyst tool in GIS environment (figure 7a-7c) and (figure 8a-8c) respectively. The geology maps for the study districts has been prepared with the help of digitization process from referenced geological map which has been collected from Geological Survey of India (figure 9a-9c). The thematic layers of soil for study districts are generated with the help of digitization process from referenced soil map collected from National Bureau of Soil and Land Use Department (figure 10a-10c). The distance from road and distance from settlements for study districts are prepared with the help of Euclidian distance buffering tool in GIS environment (figure 11a-11c) and (figure 12a-12c).

To prepare the LULC map of Tehri, LISS 4 images of 16-FEB-2020 (5m × 5m) is procured from NRSC Data center (NDC) and the map was prepared by using a supervised classification tool in ERDAS imagine 2013 (figure 13a). In order to achieve good accuracy of land cover map and resolve some cases of class confusion, recoding process is applied in ERDAS imagine 2013. The recoding tool changes the pixel character of a selected class area permanently into another class pixel. Each recoded class area was verified through Google Earth, and new values were inserted to a column. As a result, an improved land cover map is obtained. The ground truth points are obtained from field surveys using GPS device. A total of 150 points were compared with the classified land cover map and an error matrix was generated. LULC maps of Rudraprayag and Chamoli are prepared using ESRI published LULC data (figure 13b-13c).

The normalized differential vegetation index (NDVI) of study area is calculated from Landsat 8 OLI image with the help of image analysis tool in ArcGIS software (figure 14a-

14c). The thematic layer of TWI is prepared from SRTM DEM imagery in GIS environment using Eq. 1which was suggested by Moore et al. (1991).

$$\text{TWI} = \ln\left(\frac{\alpha}{\tan_{\beta}}\right) \qquad \text{Eq.1}$$

Where, TWI = topographic wetness index, α is cumulative upslope area draining through a point (per unit contour length), β is the slope gradient (in degree).

The drainage density of the study area is calculated using the line density analysis tool in Arc GIS software. The drainage density map of the Tehri Garhwal, Rudraprayag and Chamoli is presented in (figure 15a-15c).

Land surface temperature (LST) of all districts under study area (figure 16a-16c) is calculated using Landsat 8 data. Firstly, the Digital numbers were converted to spectral radiance using radiance rescaling factors provided in the metadata file, by the following formula (Eq. 2).

$$L(\lambda) = gain * DN + offset \qquad \text{Eq.2}$$

The second step is to transform the spectral radiance to at-satellite brightness temperature using the thermal constant, by the following formula (Eq. 3).

$$T = \frac{K2}{Ln\left(\frac{K1}{L\lambda}+1\right)} - 272.15 \qquad \text{Eq.3}$$

Where T is the at-satellite brightness temperature (K); K1 and K2 are calibration constants. For Landsat-8 Thermal Infrared Sensor (TIR), band10 K1 value is 774.89K and K2 480.89K whereas, band 11 K1 value 1321.08K and K2 1201.14K (Patil et al. 2018).

The last step is the calculation of land surface temperature (Eq.4).

$$LST = BT/1 + w*(BT/p)*In(e) \qquad \text{(Eq. 4)}$$

Where, BT= At satellite Temperature, w = wavelength of emitted radiance in meters, p= constant value 14380 and e= emissivity (Eq. 5).

Land Surface Emissivity=0.004+ProVeg+0.986 (Eq. 5)

Where the proportion of vegetation (Pv) can be calculated as (Eq.6).

Proportion Vegetation = (NDVI+NDVImin/ NDVImax-NDVImin)2 (Eq. 6)

Geomorphology map of the study districts are prepared with the help of digitization process from referenced map which has been collected from Geological Survey of India (figure 18a-18c) in Arc GIS software.

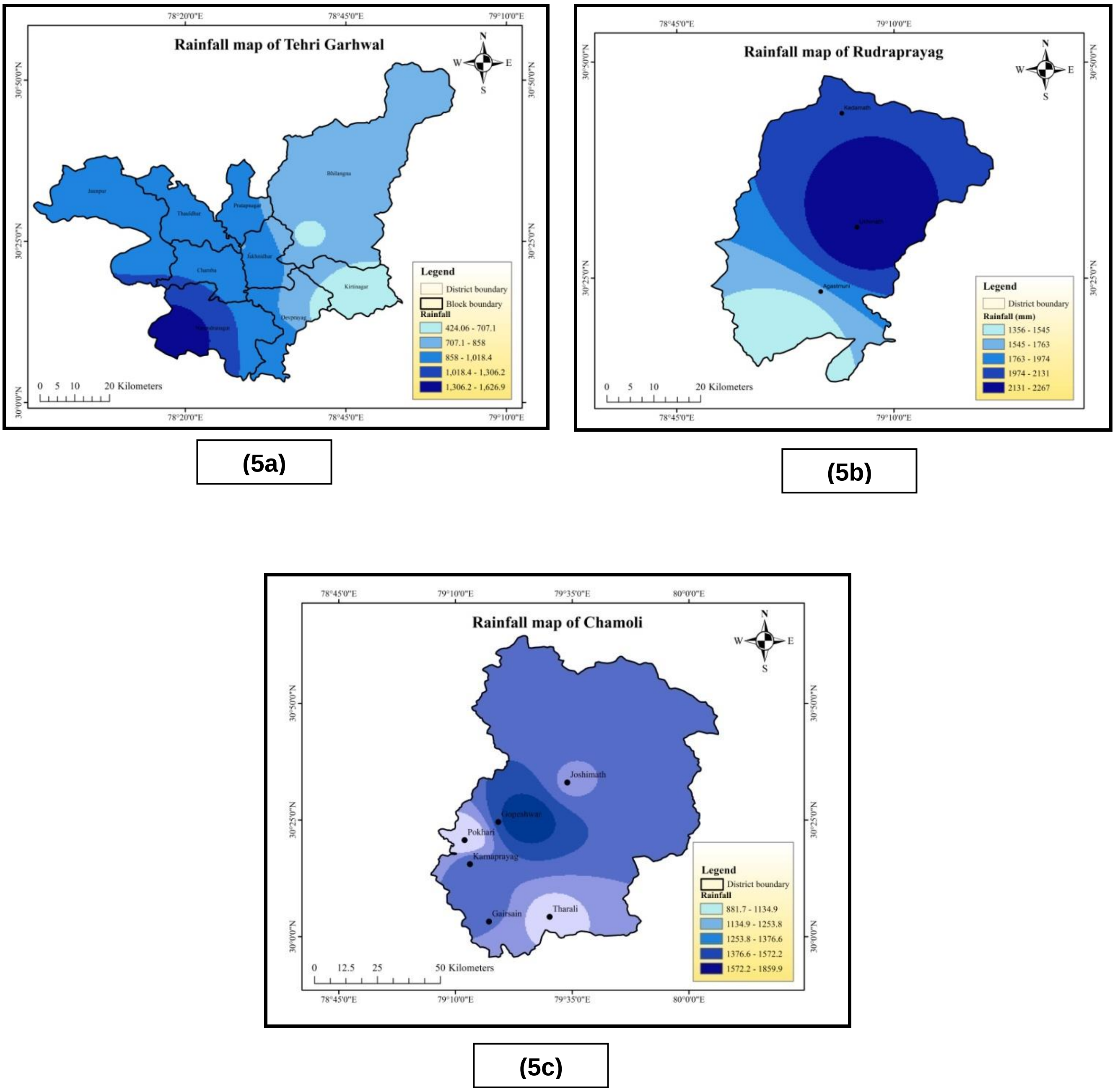
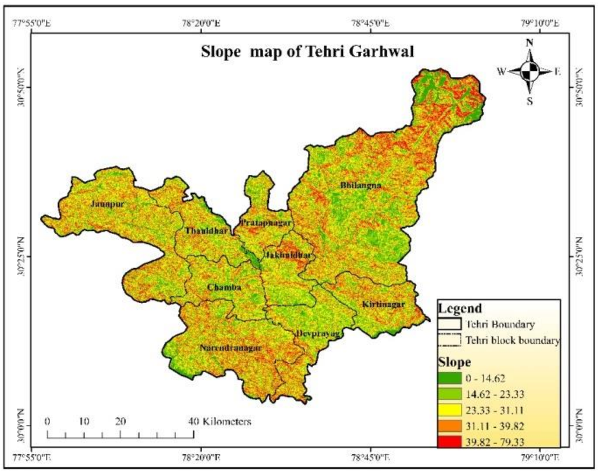
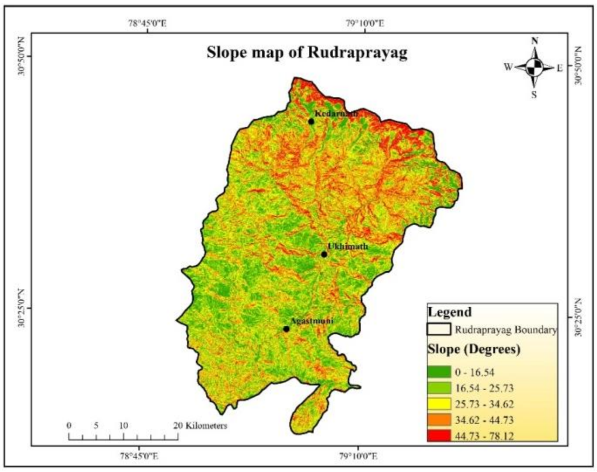


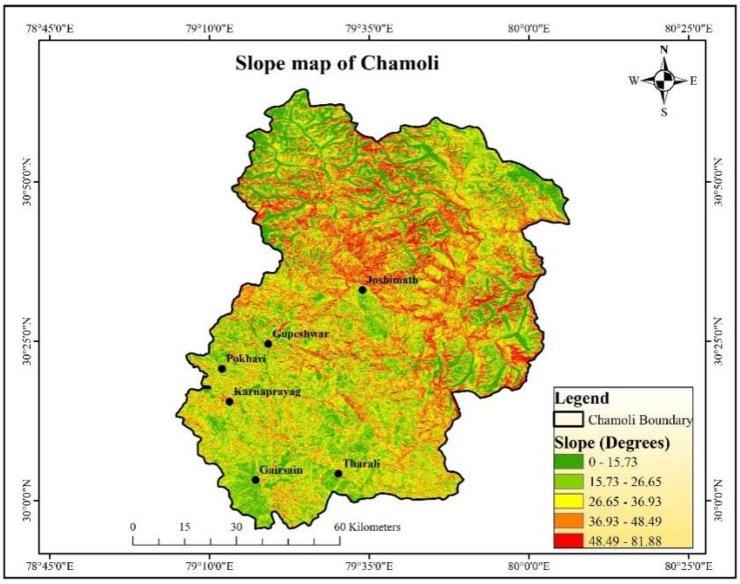
Figure 5: Rainfall map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(6a)

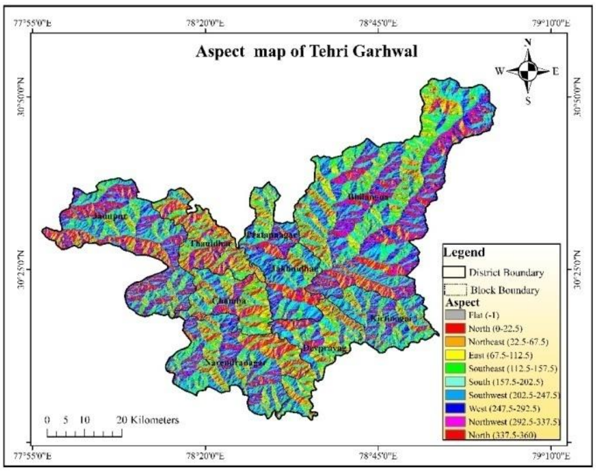


(6b)

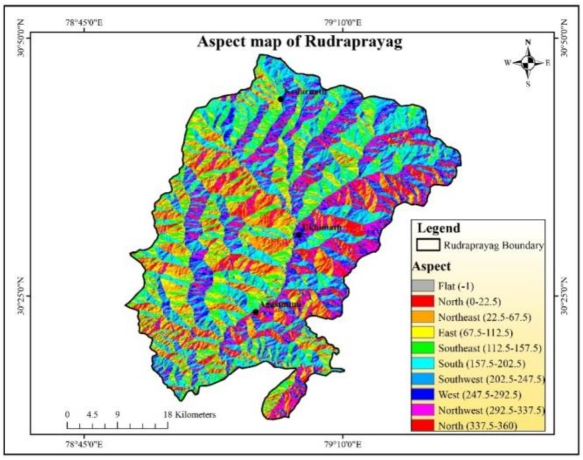


(6c)

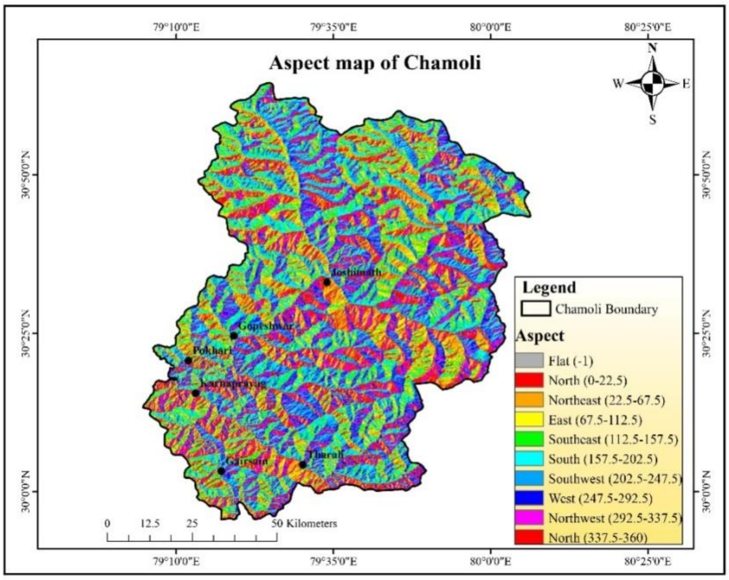
Figure 6: Slope map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(7a)

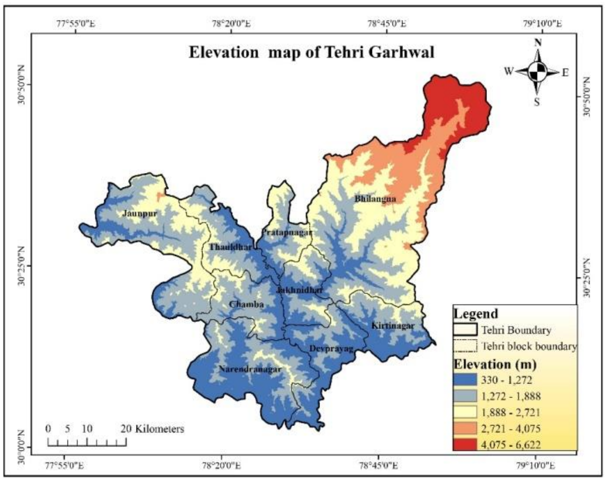


(7b)

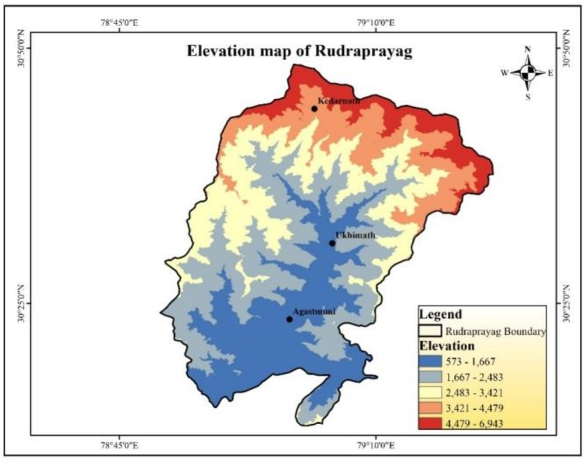


(7c)

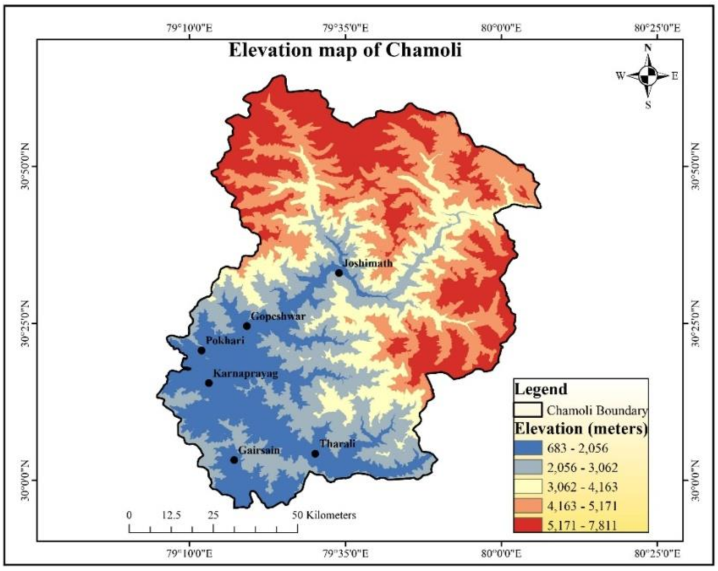
Figure 7: Aspect map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(8a)

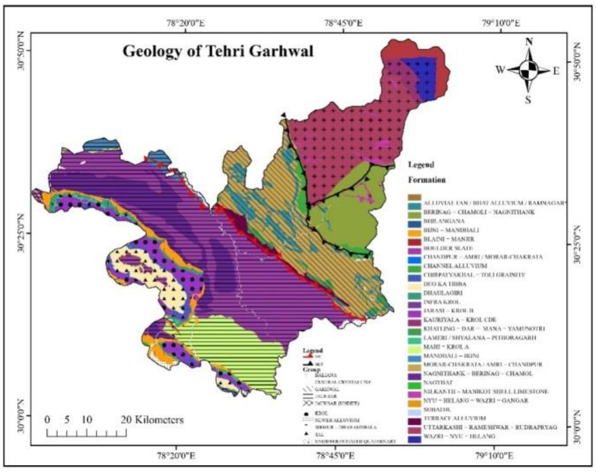


(8b)

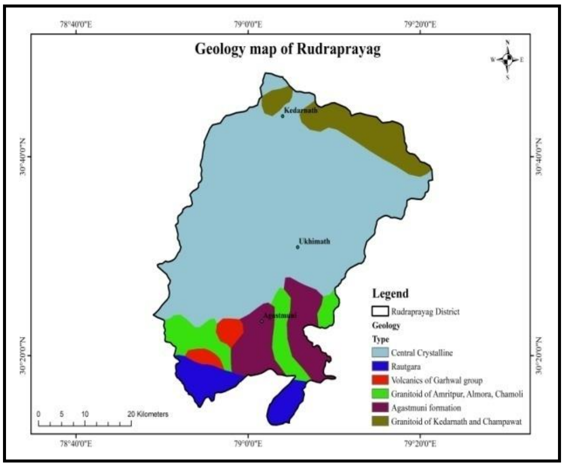


(8c)

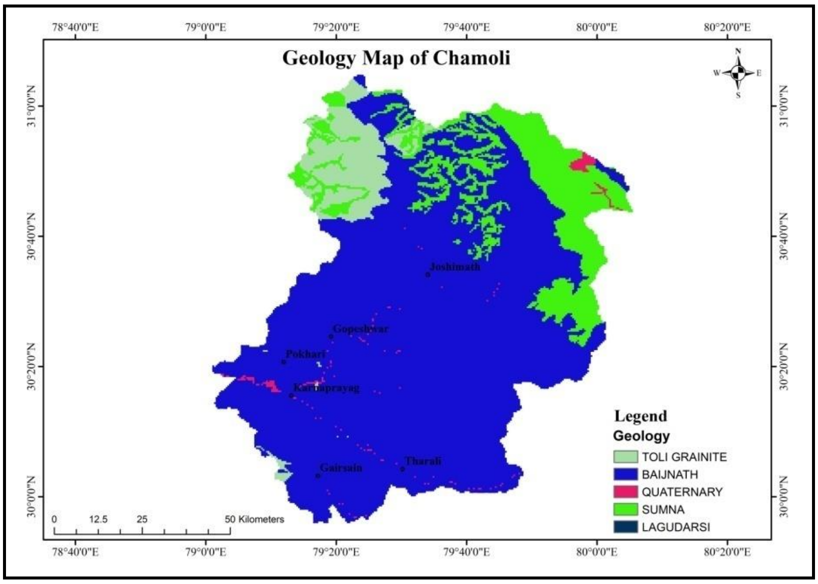
Figure 8: Elevation map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(9a)



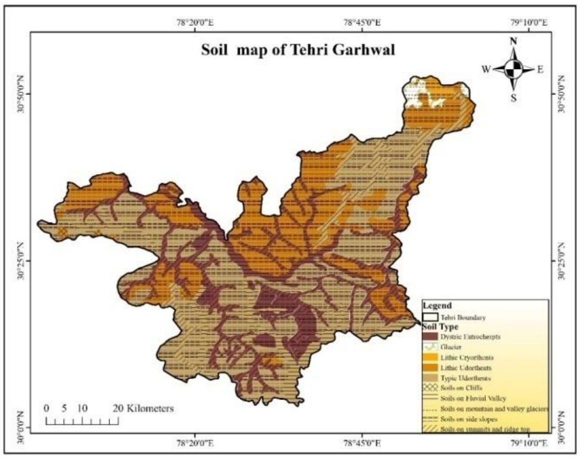
(9b)



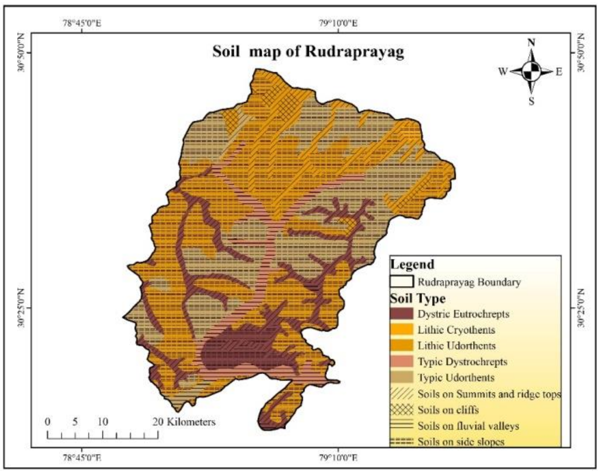
(9c)

***Source: Prepared from published map of Geological survey of India, Kolkata (1:250000)**

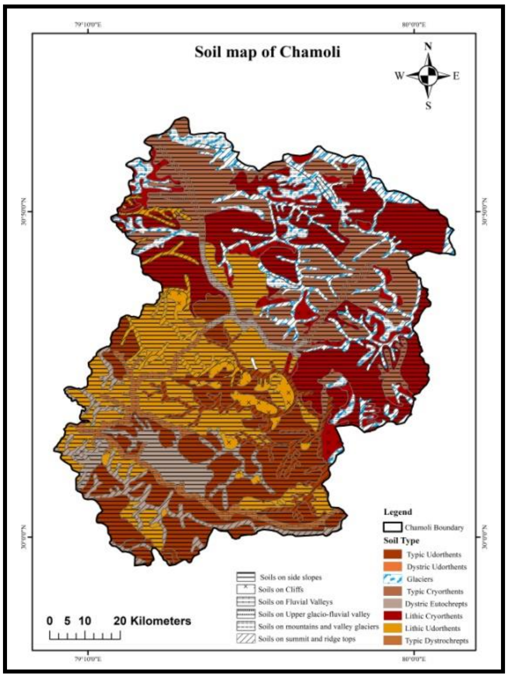
Figure 9: Geology map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(10a)



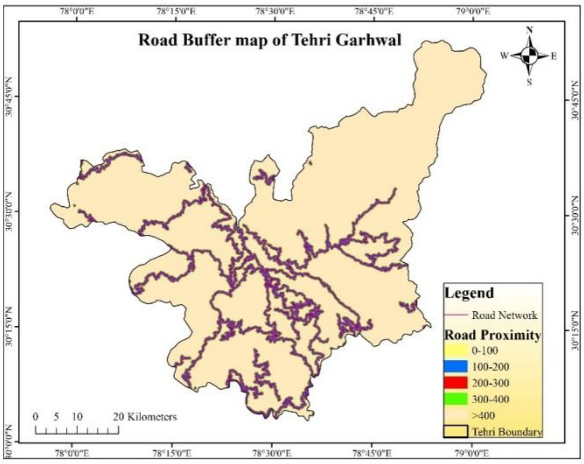
(10b)

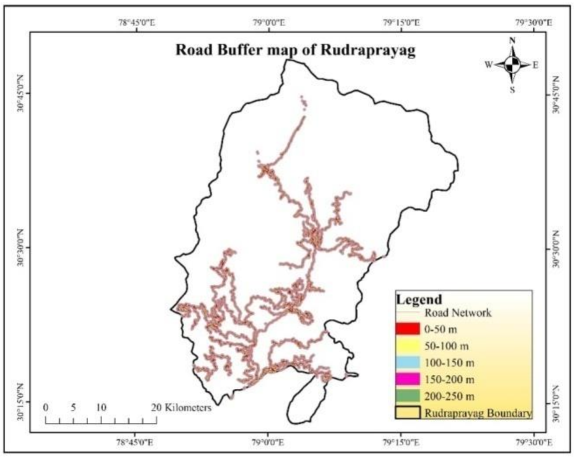


(10c)

***Source: Prepared from Published map of National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur (Scale 1: 500000)**

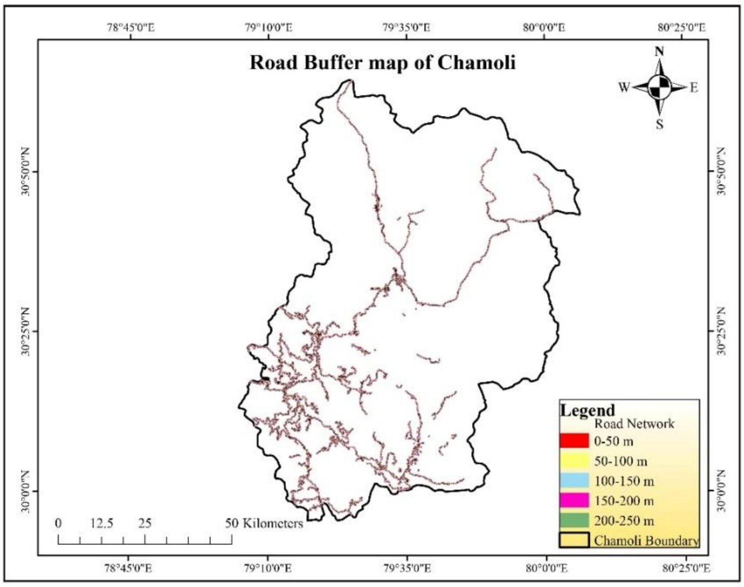
Figure 10: Soil map of (a) Tehri Garhwal (b) Rudraprayag (c) Chamoli





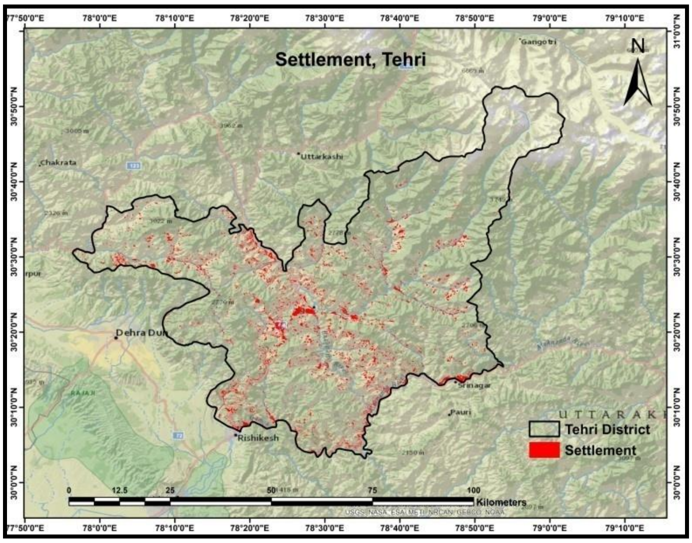
(11a)

(11b)

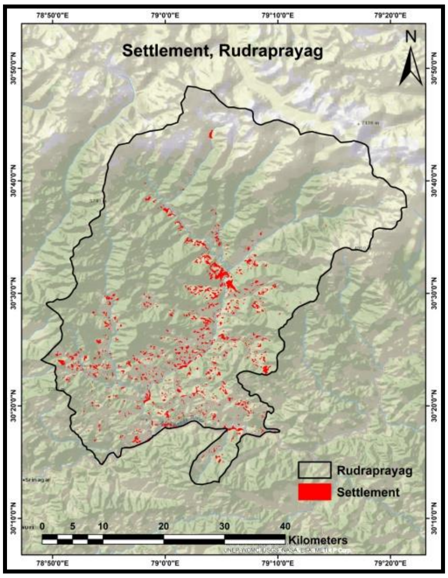


(11c)

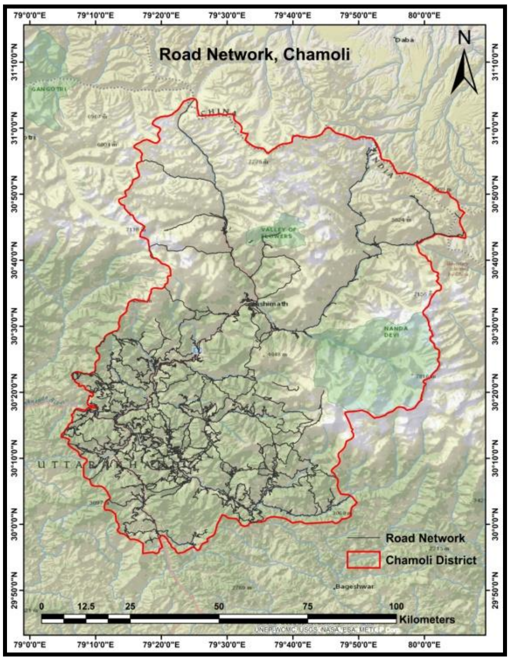
Figure 11: Road map of (a) Tehri Garhwal (b) Rudraprayag (c) Chamoli



(12a)

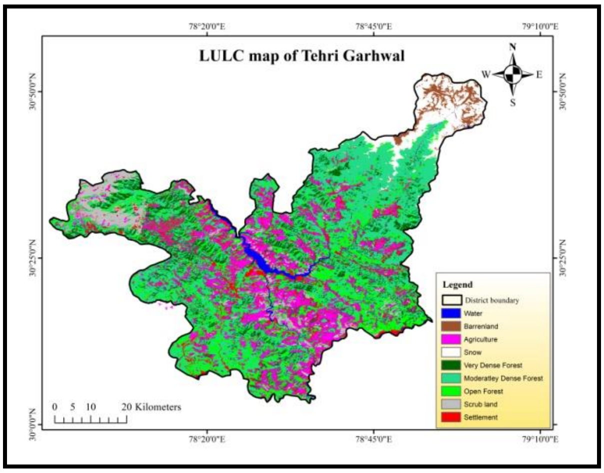


(12b)

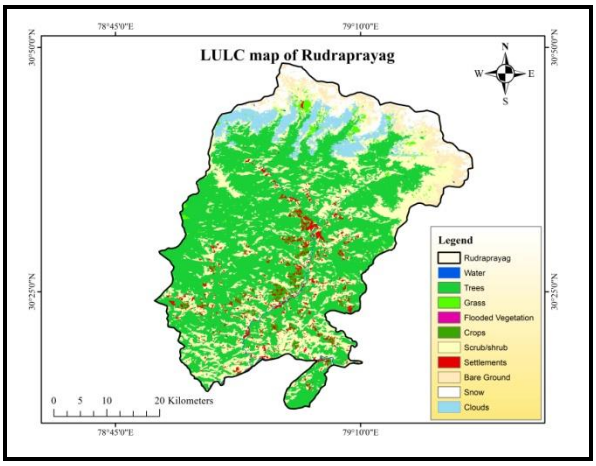


(12c)

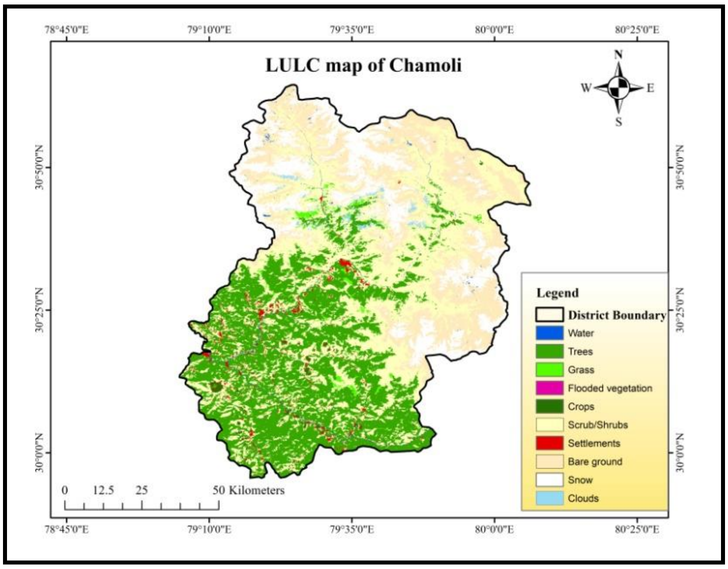
Figure 12: Settlements map of (a) Tehri Garhwal (b) Rudraprayag (c) Chamoli



(13a)

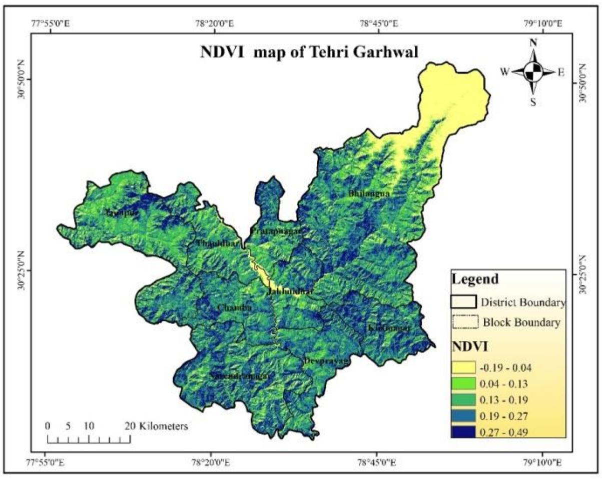


(13b)

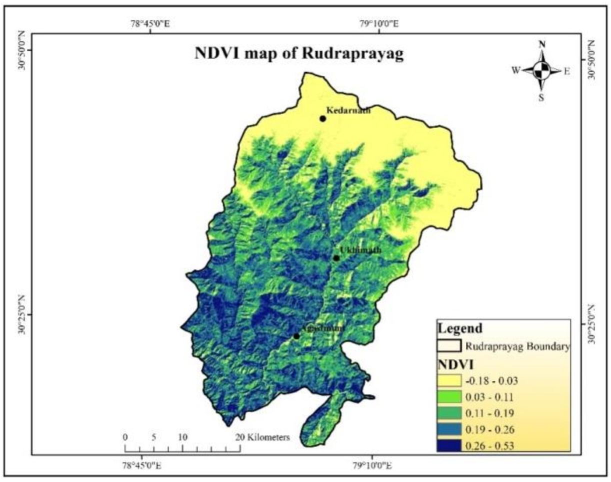


(13c)

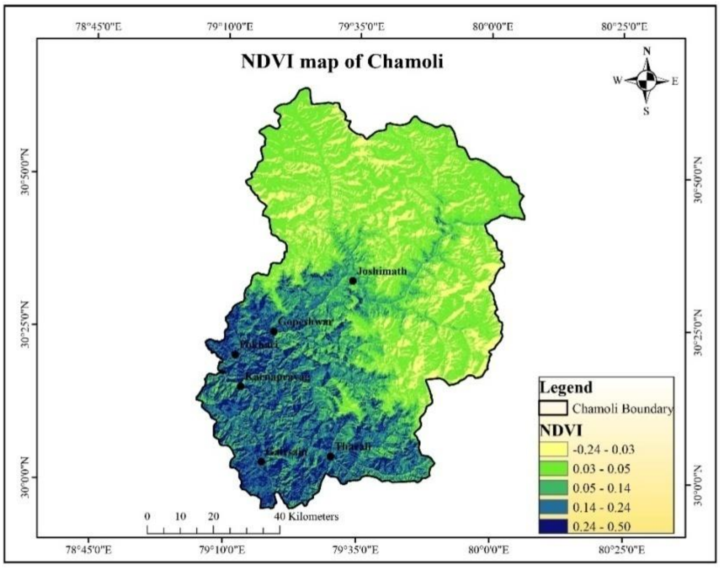
Figure 13: LULC map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(14a)

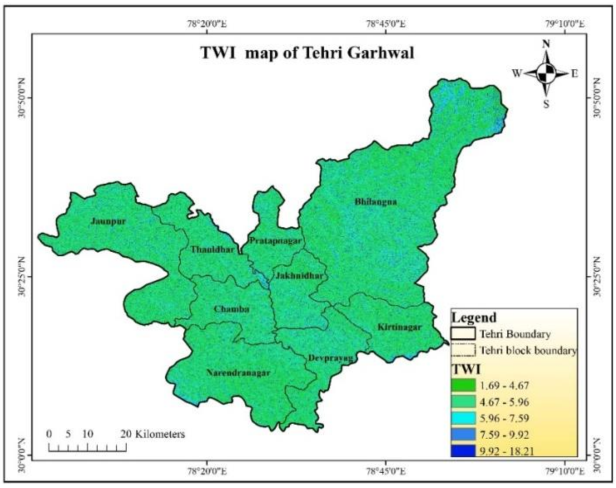


(14b)

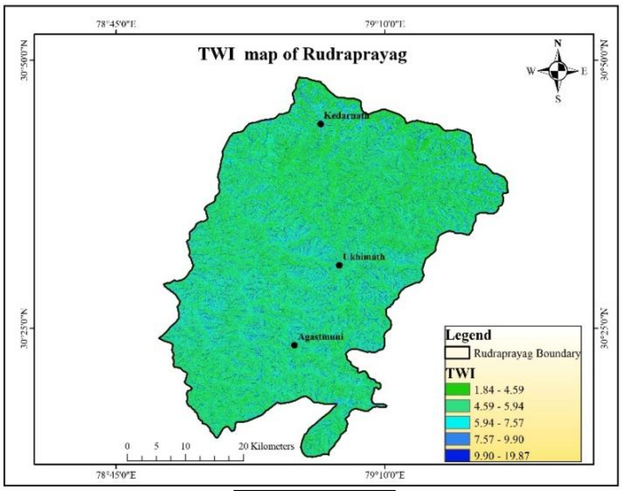


(14c)

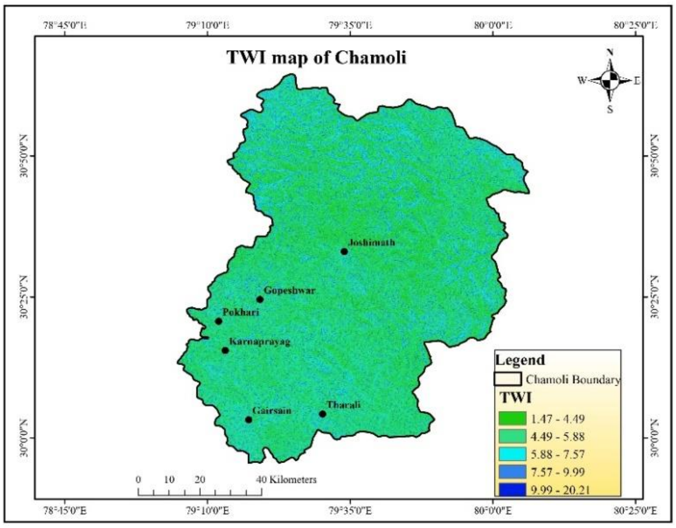
Figure 14: NDVI map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(15a)

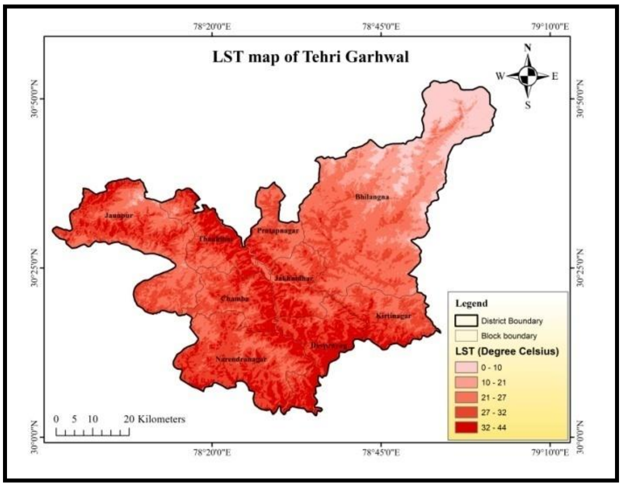


(15b)

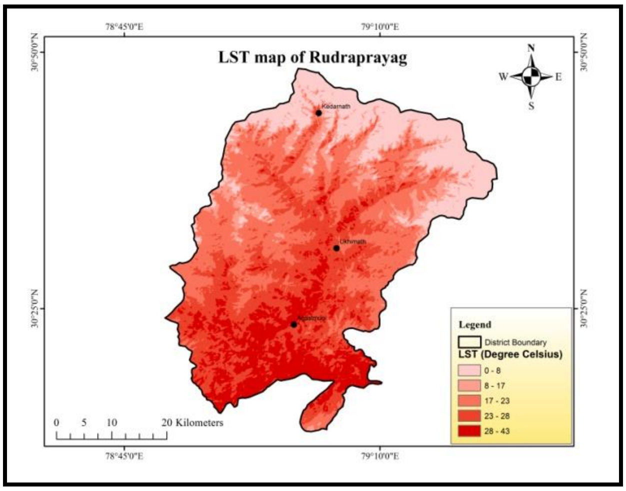


(15c)

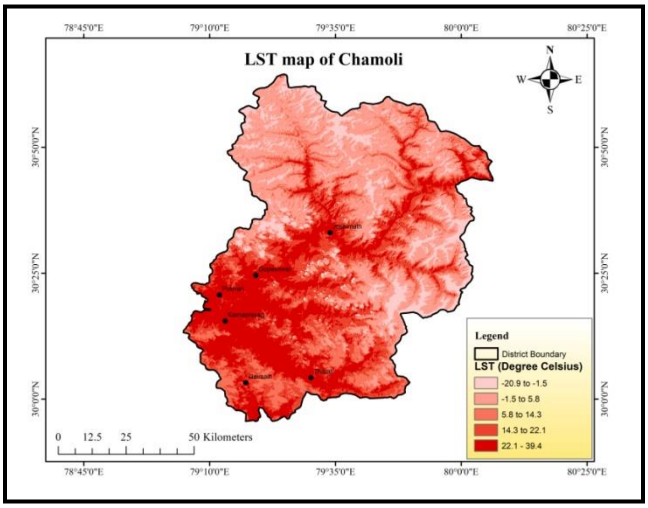
Figure 15: TWI map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(16a)

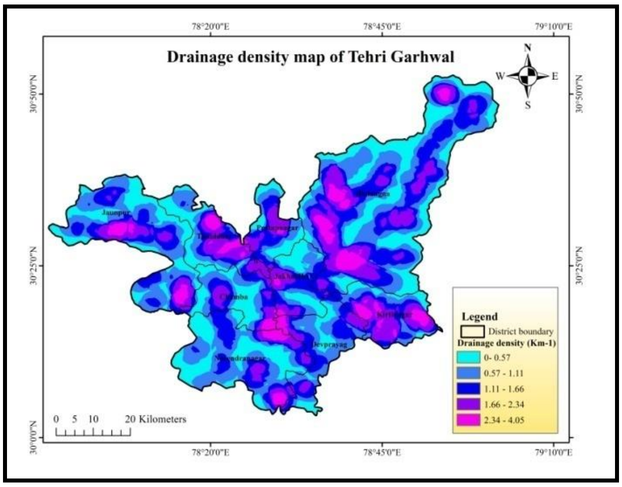


(16b)

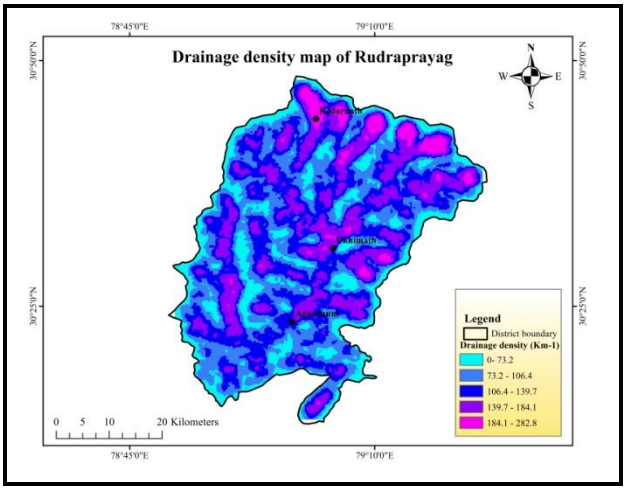


(16c)

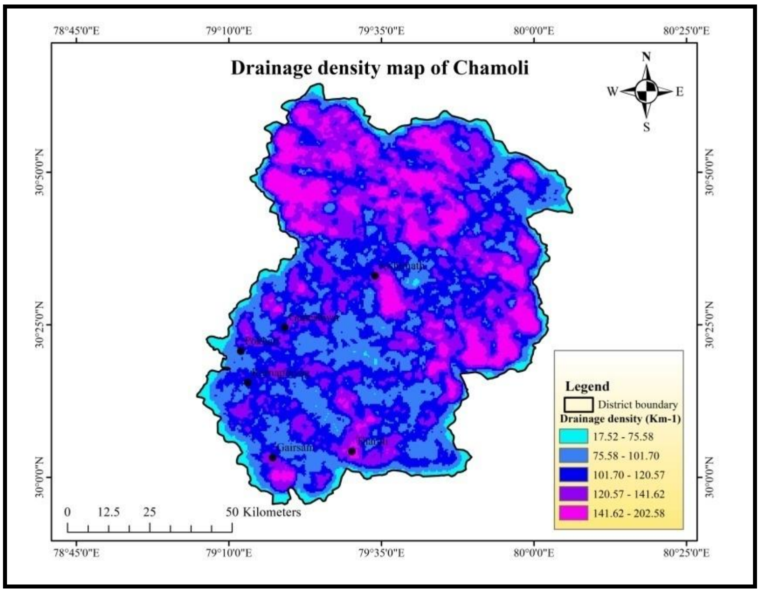
Figure 16: Land Surface Temperature (LST) map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(17a)

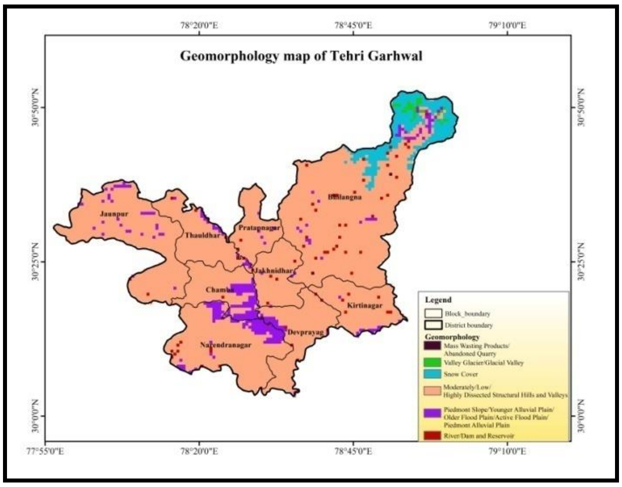


(17b)

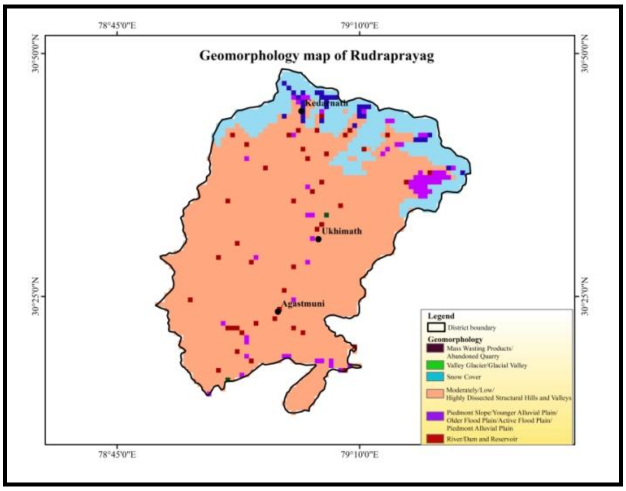


(17c)

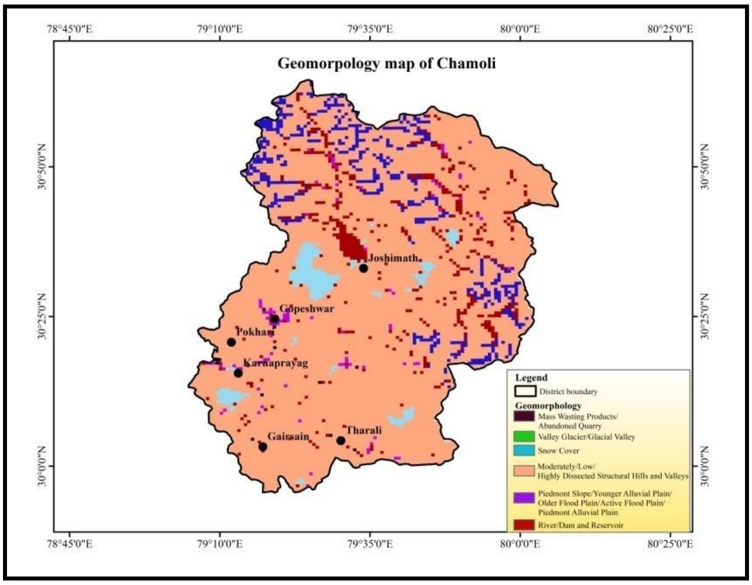
Figure 17: Drainage density map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli



(18a)



(18b)



(18c)

Figure 18: Geomorphology map of (a) Tehri Garhwal (b) Rudraprayag and (c) Chamoli

Analytical Hierarchy Process (AHP)

In this study, the Analytical Hierarchy Process (AHP) technique is used to synthesize the landslides, forest fire and flash flood susceptibility maps of the study area. Application of AHP is widely accepted method for site selection, suitability analysis and landslide susceptibility mapping over the years (Ayalew et al. 2005, Yalcin 2008, Feizizadeh and

Blaschke 2012, Kumar and Anbalagan 2016, Xiong et al., 2017, El Jazouli et al. 2019, Li et al., 2021).

AHP is a multi-decision criterion analysis (MCDA) method which involves generation of pair wise comparison matrix, calculation of criteria weights and estimation of consistency ratio. Pair wise comparison matrix involves weight assignment of different criteria on a nine point based ordinal scale (Table 1) by means of pair wise comparison between them.

Table 1 Numerical scale for pair wise comparison (Saaty, 1977)

Preference/Scale	**Degree of preference**	**Remarks**
1	Equally	Factors inherit equal contribution
3	Moderately	One factor moderately favored over other
5	Strongly	Judgment strongly favored over other
7	Very strongly	One factor very strongly favored over other
9	Extremely	One factor favored other in highest
2,4,6,8	Intermediate	Compensation between 1,3,5,7 and 9
Reciprocals	Opposite	Inverse comparison

In AHP method, factors are arranged in the form of a matrix having equal rows and columns where, scores are provided on one side of the diagonal and values of 1 is provided in the diagonal of the matrix (Satty, 1977). According to Yalcin (2008), both subjective and objective approach should be taken into consideration in decision making process. In this study, relative scores to landslide causative factors and their classes are determined on the basis of literature review, expert opinion and incidences of landslide locations in these classes. When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 and 9 and conversely, the value varies between the reciprocals 1/2 and 1/9 (Saaty 1980; Yalcin 2008).

The factors which are assigned different weights may sometimes be subjective in nature. In order to overcome this subjectivity, AHP facilitates the calculation of consistency index (CI) and consistency ratio (CR).

CI was formulated by Satty (1980) as (Eq 7):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad \text{(Eq 7)}$$

Where, λ_{max} is maximum eigen values and n is number of elements present in each column or row of the matrix.

CR is defined as the ratio between the consistency index (CI) and random index (RI) (Eq 8).

$$CR = \frac{CI}{RI} \quad \text{(Eq. 8)}$$

RI is the consistency index of the randomly generated pair wise comparison matrix. Saaty (1980) compiled RI on the basis of the number of random samples (Table 2).

Table 2 Random Consistency Index (RI) (Satty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

The CR value of 0.1 or less is considered acceptable. Higher CR values indicate that the judgments are not compatible and comparison matrix should be retrieved again.

Validation: To check the accuracy and prediction potential of applied model, it is essential to perform the validation. In present study, Receiver operative curve (ROC) method is used to validate the final output i.e. hazard susceptibility map.

ROC is prepared by using two statistical indices value such as sensitivity (Eq. 9) (represented by Y axis) and 1-specificity (Eq. 10) (represented by X- axis) against each other.

$$\text{Sensitivity (Y)} = \left(\frac{True\ Positive}{True\ positive + False\ negative}\right) \quad \text{(Eq.9)}$$

$$\text{Specificity (X)} = 1 - \left(\frac{True\ Negative}{True\ negative + False\ positive}\right) \quad \text{(Eq. 10)}$$

The accuracy of the model to forecast the occurrence and non-occurrence of the landslides is determined by the area under the ROC curve (AUC). A model is said to be good fit if it has AUC values ranging from 0.5 to 1, whereas AUC value less than 0.5 is considered as random fit (Mathew et al., 2007).

Objective 2: Quantification of disproportionate opportunities of women in disaster management.

Reconnaissance survey and sampling:

Reconnaissance survey was conducted in the selected areas identified from the multi hazard susceptibility maps. For Tehri Garhwal, multi hazard susceptibility map suggested that Kirtinagar block has highest multi hazard susceptibility, followed by Bhilangana, Pratapnagar and Jakhni dhar. Therefore, these blocks are considered for collection of data. For Rudraprayag districts, Ukhimath and Agastmuni blocks were selected purposely due to its proneness to the multi hazards. Similarly, For Chamoli district, Joshimath, Karanparayg and Gairsain blocks are selected owing to their multi hazard susceptibility. Villages with the history of repeated history of natural disasters from each selected blocks of the districts were identified for collection of data. Table 3 summarizes the characteristics of the villages selected for the collection of data.

Table 3: Information about the selected villages

District	Block	Name of the villages	Number of households	Total Population	Male population	Female population
Tehri	**Kirtinagar**	Neuli	33	141	57	84
		Kothar	191	950	426	524
		Thati Dagar	241	1216	548	668
	Bhilangana	Ghansali	82	392	200	192
		Kot	56	231	101	130
		Chamiyala	502	2602	1172	1430
		Bhatgaon	133	711	359	352
	Jakhnidhar	Bhatwara	87	400	181	219
		Kolgaon	28	125	57	68
		Kandogi	27	149	54	95
	Pratapnagar	Gwar	25	78	37	41
		Pokhari	118	664	337	327
		Raulakot	140	603	273	330
Rudraprayag	**Ukhimath**	Chunni	59	286	161	125
		Kimana	88	393	192	201
		Ukhimath	511	2296	1184	1112
		Mangoli	54	246	124	122
		Sansari	34	211	129	82

	Agastmuni	Tinsoli	114	483	209	274
		Sera	26	127	57	70
		Kalai	28	136	55	81
		Bhatwari	62	260	133	127
		Basti	218	1074	526	548
Chamoli	**Joshimath**	Bhenta	67	346	183	163
		Bampa	60	192	85	107
		Kimana	100	450	227	223
	Karanprayag	Jakh	138	603	273	330
		Simli	94	413	213	200
		Kameda	77	336	158	178
	Gairsain	Mathar	51	204	89	115
		Silapata	77	368	160	208
		Sarkot	218	1236	568	668
	Tharali	Silaudi	105	462	225	237
		Ratgaon Chak	245	1256	599	657
		Kulsari	117	476	248	228

Questionnaire Survey: Questionnaire was developed using close ended, open and multiple choice questions. The first part of the questionnaire included the socio-demographic characteristics of the interviewees to assess the social background of the respondents and their gender. Subsequent sections included questions related to risk awareness, preparedness, rescue management and assistance, information and education. The questionnaire survey was conducted in the selected villages during 2020-2022 through mixed (Structures and semi structured) household level questionnaire and focused group discussions with the women. Total 960 respondents from 32 selected villages of 10 blocks are interviewed to collect data in order to quantify the disproportionate opportunities of women in disasters. Stratified random sampling was adopted in drawing the sample from the study area.

Objective 3: To identify the multi-hazard induced vulnerabilities by the local communities with special reference to women in the area.

Key informant's interviews: Interviews with current village heads, former village heads and female school teachers were also carried out to capture climatic perceptions and impacts of natural disasters. Wherever possible, government officials from the district/block were also interviewed. Across the study villages, 12 interviews were carried out.

Focused Group Discussions:

Gender disaggregated focus group discussions were organized for women exposed to different climatic hazards. Participants first discussed perceptions of differentiated impacts arising out of various climatic risks along with asset ownership, social roles and relations within community. Two focused group discussions (FGDs) in each district were conducted which involves 20-25 people in each FGD. Focused group discussions involved representatives from self-help groups (SHGs) and village heads. FGDs helped to identify and understand the barriers and factors making women vulnerable to natural disasters.

2.2 Details of scientific data collected and equipments used

Detailed description of the scientific data collected and methods used for the preparation of thematic layers and hazard inventory is given in Table 4.

S.No.	Parameters/Thematic maps	Data Type in GIS	Tools/formulae used in GIS	Scale/Resolution	Source
1.	Landslide inventory	Polygon/points	Visual interpretation and Digitization	5.8 m	IRS P6 LISS4, Field visits, Bhukosh
2.	Forest fire inventory	Point data			Field visits, MODIS
3.	Flash flood inventory	Point data			Published papers/reports, news papers
2	Rainfall	Grid	Inverse Distance Weighting (IDW) interpolation		Indian Meterological Department (IMD)
3.	Slope	Grid	Spatial Analyst	30 m × 30 m	Shuttle Radar Topography Mission (SRTM)
4.	Aspect	Grid	Spatial Analyst	30 m × 30 m	Shuttle Radar Topography Mission (SRTM)
5.	Elevation	Grid	Spatial Analyst	30 m × 30 m	Shuttle Radar Topography Mission (SRTM)
6.	Geology	Polygon	Digitization	1:250,000	Geological map from Geological Survey of India(GSI)

7.	Soil	Polygon	Digitization	1:500,000	National Bureau of Soil Survey and Land Use Planning (NBSSLUP)
8.	Normalized Difference Vegetation Index (NDVI)	Grid	Image Analysis using following formula: $NDVI = \frac{NIR - Red}{NIR + Red}$	30 m × 30 m	Landsat OLI 8
9.	Topographic Wetness Index (TWI)	Grid	Hydrology tool using following formula: $TWI = ln\left(\frac{\alpha}{tan_{\beta}}\right)$	30 m × 30 m	Shuttle Radar Topography Mission (SRTM) DEM
10.	Land Use/Land cover	Grid	Supervised classification	10 m × 10 m (For Rudraprayag and Chamoli) 5 m × 5m (For Tehri Garhwal)	ESRI lulc map for Rudraprayag and Chamoli LISS 4 for Tehri Garhwal
10.	Roads	Polyline	Digitization		Toposheet, Google Earth, Bhukosh
13.	Drainage Proximity	Polygon	Buffer under Geo processing tool		Drainage map

2.3 Details of Field survey arranged

Based on the literature review of research articles, government reports, discussions with block office officials each district under study; field survey was conducted to record the locations of past landslides. Some of the photos taken during the field survey are attached in annexure I.

The questionnaire survey was conducted in the selected villages during 2020-2022 through mixed (Structures and semi structured) household level questionnaire and focused group discussions with the women. Total 960 respondents from 32 selected villages of 10 blocks are interviewed to collect data in order to quantify the disproportionate opportunities of women in disasters.

2.5 Strategic Planning for each Activity

2.6 Activity-wise Timeframe followed using Gantt/Pert Chart

S.No.	Activities	1st year				2nd year				3rd year			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Collection and collation of literature												
3	Reconnaissance survey for identifying the locations of natural disasters in the study area												
4	Collection of primary and secondary data regarding natural disasters												
5	Data evaluation and disaster susceptibility mapping												
6	Questionnaire survey to evaluate impact of												

	disasters on community					■	■	■	■				
7	Data evaluation and interpretation							■	■	■	■		
8	Identification of causative factors responsible for disaster induced women vulnerabilities											■	■
9	Final report submission												■

3 KEY FINDINGS AND RESULTS

3.1 Major Research Findings

<u>Objective 1: To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.</u>

Spatial distribution analysis of parameters

The annual average rainfall of the The spatial distribution of average annual rainfall of Tehri Garhwal ranges from 424.06mm to 1626.9mm and classified in to five classes through natural break method such as very low (424.06mm to 707.1mm), low (707.1mm to 858mm), medium (858mm to 1018.4mm), high (1018.4mm to 1306.2 mm) and very high (1306.2 mm to 1626.9 mm) covering 6.5%,39.2%, 18.7%,21.8% and 13.6% area respectively (Table 5).

The spatial distribution of average annual rainfall of Rudraprayag district ranges from 1356mm to 2267mm and classified into five categories through natural break as very low (1356 mm to 1545mm), low (1545 mm to 1763 mm), medium (1763 mm to 1974 mm), high (1974 mm to 2131 mm) and very high (2131 to 2267 mm) corresponding to 13.7%, 10.1%, 30.1%, 33.4% and 12.6% of the total area respectively (Table 5).

The spatial distribution of average annual rainfall of Chamoli district ranges from 881.7mm to 1859.9mm and classified into five categories through natural break as very low (881.7 mm to 1134.9mm), low (1134.9 mm to 1253.8 mm), medium (1253.8 mm to 1376.6 mm), high (1376.6 mm to 1572.2 mm) and very high (1572.2 to 1859.9 mm) corresponding to 3.4%, 7.5%, 68.4%, 14.4% and 6.2% of the total area respectively (Table 5).

Slope is the most typical and considerable parameter used in landslide susceptibility mapping. It usually contributes to a landslide by the flow of water and soil etc. (Kannan et al. 2013). Slope of Tehri district ranges up to 79.33° and classified under five classes through natural break as very low (0 to 14.620), low (14.620 to 22.330), medium (22.330 to 31.110), high (31.110 to 39.820) and very high (39.820 to 79.33°) corresponding to 12.1%, 25.5%, 31.2%, 23.6% and 7.6% of the total area respectively (Table 5).

Slope of Rudraprayag district ranges up to 78.120 and classified under five classes through natural break as very low (0 to 16.540), low (16.540 to 25.730), medium (25.730 to 34.620), high (34.620 to 44.730) and very high (44.730 to 78.12°) corresponding to 16%, 27.2%, 28.8%, 20.5% and 7.4% of the total area respectively (Table 5).

Similarly, slope of Chamoli district ranges from 0 to 81.880 and categorized under five classes through natural break as very low (0 to 15.730), low (15.730 to 26.650), medium (26.650 to 36.930), high (36.930 to 48.490) and very high (48.490 to 81.88°) corresponding to 16.5%, 25.2%, 29.7%, 19.9% and 8.7% of the total area respectively (Table 5).

Aspect helps in accelerating the activity of geomorphic processes on a slope. The accessibility of sunlight, rainfall, dryness of air, vegetation growth etc. depends on the slope aspect. In the present study, slope aspect is classified through natural break process into nine classes: flat, north, northeast, east, south-east, south, south-west, west and north-west for Tehri Garhwal, Rudraprayag and Chamoli districts.

The elevation of Tehri Garhwal district ranges from 330m to 6622m and classified into five categories through natural break as very low (330m to 1272m), low (1272m to 1888m), medium (1888m to 2721m), high (2721m to 4075m) and very high (4075m to 6622m) covering 27.3%, 35.7%, 23.1%, 8.3% and 5.7% of the total area respectively (Table 5). Elevation of Rudraprayag district ranges from 573m to 6943m and classified into five categories through natural break as very low (573m to 1667m), low (1667m to 2483m), medium (2483m to 3421m), high (3421m to 4479m) and very high (4479m to 6943m) covering 25%, 29.8%, 22.1%, 14.5% and 8.6% of the total area respectively (Table 5). Similarly, elevation of Chamoli district varied between 683m to 7811m. The elevation of Chamoli district is classified into five categories through natural break method such as very low (683m to 2056m), low (2056m to 3062m), medium (3062m to 4163m), high (4163m to 5171m) and very high (5171m to 7811m) covering 20.2%, 20.4%, 16.2%, 23.1% and 20.1% of the total area respectively (Table 5).

Loose soil, when mixed with rain water, increases the load of hillslope and causes mudflow, solifluction, etc. Different soil textures have different cohesive characteristics. There are five soil type in Tehri Garhwal (National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur) such as, Dystric Eutrochrepts, Glacier, Lithic Cryothents, Lithic Udorthents and Typic Udorthents covering 23.5%, 1.2%, 0.8%, 26.4% and 48.1% of the total area respectively (Table 2).Similarly, Rudraprayag also possess five types of soil such as Dystric Eutrochrepts, Lithic Cryothents, Lithic Udorthents,Typic Dystrochrepts and Typic Udorthents covering 16.1%, 0.5%, 46.5%, 7.5% and 29.4% of the total area respectively (Table 5). However, the Chamoli district has eight types of soil such as Lithic Cryothents, Dystric Udorthents, Typic Udorthents, Lithic Udorthents, Typic Dystrochrepts, Typic Cryothents, Glaciers, Dystric Eutrochrepts covering 22.9%, 0.01%, 20.1%, 19.1%, 3.1%, 14.7%, 12.2% and 7.9% respectively (Table 5).

The characteristics of different soil types are as follows:

Dystric Eutrochrepts: Deep well drained, fine loamy soils with loamy surface and light erosion.

Lithic Cryothents: Rock outcrops associated with very shallow, excessively drained, sandy skeletal soil on very steep slopes with sandy surface, very severe erosion and strong stoniness.

Lithic Udorthents: Shallow, excessively drained, loamy skeletal soil with loamy surface severe erosion and moderate stoniness.

Typic Udorthents: Moderately shallow, excessively drained, sandy skeletal soil with sandy surface, moderate erosion and moderate stoniness.

Typic Dystrochrepts: Deep, excessively drained, fine loamy soils on moderately steep slopes with loamy surface, moderate erosion and moderate stoniness.

Dystric Udorthents: Very shallow, excessively drained, sandy skeletal soil on very steep slopes

Typic Cryothents: Moderately shallow, excessively drained, coarse loamy soils on steep slopes with loamy surface, severe erosion, and moderate stoniness.

Landuse/landcover (LULC) of Tehri Garhwal is classified into nine classes which includes water (1.41%), barren land (3.66%), agriculture (16.8%), snow (5.96%), very dense forest (12.45%), moderately dense forest (29.57%), open forest (19.53%), scrubland (5.80%) and settlements (19.53%). About 81% of accuracy of the LULC map is obtained (Table 6).

LULC of Rudraprayag district is classified into nine classes water (0.35%), trees (54.65%), Grass (1.18%), crops (1.73 %), scrub/shrubs (24.9 %), settlements (2.92%), bare ground (4.02), snow (4.83%) and clouds (5.41%). Similarly, lulc of Chamoli district is classified into nine classes water (0.37%), trees (30.5%), Grass (0.90%), crops (0.63%), scrub/shrubs (33.35%), settlements (1.19%), bare ground (19.72), snow (12.74%) and clouds (0.63%) (Table 5).

The values of NDVI in the study area ranges from -0.19 to 0.49 in Tehri Garhwal -0.18 to 0.53 in Rudraprayag district and -0.24 to 0.50 in Chamoli. The NDVI values of all three districts are categorized into five classes through natural break method and area covered by each class is calculated (Table 5). TWI values varied from 1.69 to 18.21 for Tehri Garhwal, 1.84 to 19.87 for Rudraprayag and 1.47 to 20.21 for Chamoli district. The values of TWI are categorized under five classes (Table 5).

Drainage density of Tehri Garhwal ranges from 0 to 4.05 km-1 which are classified into five categories through natural break as very low (0 km-1 to 0.57 km-1), low (0.57 km-1 to 1.11 km-1), medium (1.11 km-1 to 1.66 km-1), high (1.66 km-1 to 2.34 km-1) and very high (2.34 km-1 to 4.05 km-1) covering 5.53%, 16.03%, 24.04%, 27.96% and 26.44 % area respectively. Drainage density of Rudraprayag ranges from 0 to 282.8 km-1 which are classified into five categories through natural break as very low (0 km-1 to 73.2 km-1), low (73.2 km-1 to 106.4 km-1), medium (106.4 km-1 to 139.7 km-1), high (139.7 km-1 to 184.1 km-1) and very high (184.1 km-1 to 282.8 km-1) covering 4.06%, 20.44%, 28.66%, 28.79%, and 18.06% of the total area respectively. Similarly, drainage density of the Chamoli district varies from 17.52 to 202.58 km-1 which are classified into five categories through natural break as very low (17.52 km-1 to 75.58 km-1), low (75.58 km-1 to 101.7 km-1), medium (101.7 km-1 to 120.57 km-1), high (120.57 km-1 to 141.62 km-1) and very high (141.62 km-1 to 202.58 km-1) covering 11.84%, 25.90%, 33.56%, 22.88% and 5.81% of the total area respectively (Table 5).

Land surface temperature (LST) of the Tehri Garhwal varies from 0 to 44 0C which is categorised under five classes using natural break method as very low (0-10 0C), low (10-21 0C), moderate (21-270C), high (27-32 0C) and very high (32-440C) covering 7.51%, 9.13%, 30.94%, 35.33% and 17.09% area respectively. LST of Rudraprayag ranges from 0 to 43 0C, which is classified under five classes suh as very low (0-80C), low (8-170C), moderate (17-230C), high (23-280C) and very high (28-43 0C), covering 16.29%, 9.15%, 30.62%, 28.49% and 15.45% .area respectively. Similary LST of Chamoli is also classified under five classes viz., very low (-20. 9 to -1.5 0C), low (-1.5 to 5.80C), moderate (5.8 to 14.30C), high (14.3 to 22.1 0C) and very high (22.1 to 39.4 0C) covering 9.27%, 30.70%, 15.34%, 20.15% and 24.55% of the area respectively (Table 5).

Table 5: Classification of parameters and corresponding area in study districts

Parameters	District	Classes	Method	Area (%)
Rainfall	Tehri Garhwal	Very Low (424.06-707.1mm)	Natural Break	6.5
		Low (707.1 – 858 mm)		39.2
		Medium (858 -1018.4 mm)		18.7
		High (1018.4 -1306.02 mm)		21.8
		Very High (1306.02 -1626.9mm)		13.6
	Rudraprayag	Very low (1356- 1545 mm)	Natural Break	13.7
		Low (1545 - 1763 mm)		10.1
		Medium (1763 -1974 mm)		30.1
		High (1974-2131 mm)		33.4
		Very high (2131-2267 mm)		12.6
	Chamoli	Very low (881.7-1134.9mm)	Natural Break	3.44
		Low (1134.9-1253.8mm)		7.50
		Medium (1253.8-1376.6mm)		68.41
		High (1376.6-1572.2 mm)		14.40
		Very high (1572.2-1859.9 mm)		6.25
Slope	Tehri Garhwal	Very low (0 -14.620)	Natural Break	12.1
		Low (14.620- 22.330)		25
		Medium (22.330 -31.110)		31.2
		High (31.110 -39.820)		23.6
		Very high (39.820 - 79.33°)		7.6
	Rudraprayag	Very low (0 -16.540)	Natural Break	16
		Low (16.540 -25.730)		27
		Medium (25.730 -34.620)		28.8
		High (34.620 -44.730)		20.5
		Very high (44.730 - 78.12°)		7.4
	Chamoli	Very low (0 -15.730)	Natural Break	16.5
		Low (15.730 - 26.650)		25.2
		Medium (26.650 - 36.930)		29.7
		High (36.930 - 48.490)		19.9
		Very high (48.490 - 81.88°)		8.7

Elevation	Tehri Garhwal	Very low (330m- 1272m)	Natural Break	27.3
		Low (1272m -1888m)		35.7
		Medium (1888m - 2721m)		23.1
		High (2721m - 4075m)		8.3
		Very high (4075m - 6622m)		5.7
	Rudraprayag	Very low (573m - 1667m)	Natural Break	25
		Low (1667m -2483m)		29.8
		Medium (2483m - 3421m)		22.1
		High (3421m - 4479m)		14.5
		Very high (4479m -6943m)		8.6
	Chamoli	Very low (683m -2056m)	Natural Break	20.2
		Low (2056m - 3062m)		20.4
		Medium (3062m - 4163m)		16.2
		High (4163m - 5171m)		23.1
		Very high (5171m - 7811m)		20.1
Geology	Tehri Garhwal	Jaunsar	Geological units	43.4
		Baliana		4.3
		Central crystalline		18.9
		Garhwal		22.2
		Jaunsar(undiff)		0.004
		Krol		5.1
		Newer Alluvium		0.8
		Sirmur=Dharamshala		0.2
		Tal		4.6
		Undifferentiated Quarternary		0.4
Soil	Tehri Garhwal	Dystric Eutrochrepts	Soil type classes	23.5
		Glacier		1.2
		Lithic Cryorthents		0.8
		Lithic Udorthents		26.4
		Typic Udorthents		48.1
	Rudraprayag	Dystric Eutrochrepts	Soil type classes	16.1
		Lithic Cryothents		0.5

		Lithic Udorthents		46.5
		Typic Dystrochrepts		7.5
		Typic Udorthents		29.4
	Chamoli	Lithic Cryothents	Soil type classes	22.95
		Dystric Udorthents		0.01
		Typic Udorthents		20.07
		Lithic Udorthents		19.08
		Typic Dystrochrepts		3.13
		Typic Cryorthents		14.72
		Glaciers		12.16
		Dystric Eutrochrepts		7.87
LULC	Tehri Garhwal	Water	Land use type	1.41
		Barren land		3.66
		Agriculture		16.80
		Snow		5.96
		Very Dense forest		12.45
		Moderately Dense forest		29.57
		Open forest		19.53
		Scrub land		5.80
		Settlements		4.82
	Rudraprayag	Water	Land use type	0.35
		Trees		54.65
		Grass		1.18
		Crops		1.73
		Scrub/shrubs		24.9
		Settlements		2.92
		Bare ground		4.02
		Snow		4.83
		Clouds		5.41
	Chamoli	Water	Land use type	0.37
		Trees		30.47
		Grass		0.90

		Crops		0.63
		Scrub/shrubs		33.35
		Settlements		1.19
		Bare ground		19.72
		Snow		12.74
		Clouds		0.63
NDVI	Tehri Garhwal	Very Low (-0.19-0.03)	Natural Break	13.7
		Low (0.03-0.12)		15.3
		Medium (0.12-0.19)		26.9
		High (0.19-0.26)		27.7
		Very High (0.26-0.48)		16.4
	Rudraprayag	Very low (-0.18-0.03)	Natural Break	28.8
		Low (0.03-0.11)		13
		Medium (0.11-0.19)		20.5
		High (0.19-0.26)		23
		Very high (0.26-0.53)		14.8
	Chamoli	Very Low (-0.24-0.03)	Natural Break	17.6
		Low (0.03-0.05)		44.1
		Medium (0.05-0.14)		13
		High (0.14-0.24)		15
		Very High (0.24-0.50)		10.3
TWI	Tehri Garhwal	Very Low (1.69-4.67)	Natural Break	35
		Low (4.67-5.96)		35.8
		Medium (5.96-7.59)		18.9
		High (7.59-9.92)		7.4
		Very High (9.92-18.21)		2.8
	Rudraprayag	Very Low (1.84-4.59)	Natural Break	33
		Low (4.59-5.94)		36.6
		Medium (5.94-7.57)		19.5
		High (7.57-9.90)		8.1
		Very High (9.90-19.87)		2.8
	Chamoli	Very Low (1.47-4.49)	Natural	32.4

		Low (4.49-5.88)	Break	36.4
		Medium (5.88-7.57)		19.7
		High (7.57-9.99)		8.4
		Very High (9.99-20.21)		3.1
Drainage density	Tehri Garhwal	Very Low (0-0.57 km-1)	Natural Break	5.53
		Low (0.57-1.10 km-1)		16.03
		Medium (1.10-1.66 km-1)		24.04
		High (1.66-2.34 km-1)		27.96
		Very High (2.34-4.05 km-1)		26.44
	Rudraprayag	Very Low (0-73.2 km-1)	Natural Break	4.06
		Low (73.2-106.4km-1)		20.44
		Medium (106.4-139.7km-1)		28.66
		High (139.7-184.1km-1)		28.79
		Very High (184.1-282.8km-1)		18.06
	Chamoli	Very Low (17.52-75.58 km-1)	Natural Break	11.84
		Low (75.58-101.70 km-1)		25.90
		Medium (101.70-120.52 km-1)		33.56
		High (120.52-141.62 km-1)		22.88
		Very High (141.62-202.58 km-1)		5.81
Land surface temperature	Tehri Garhwal	Very Low (0-10 0C)	Natural Break	7.51
		Low (10-21 0C)		9.13
		Medium (21-27 0C)		30.94
		High (27-32 0C)		35.33
		Very High (32-440C)		17.09
	Rudraprayag	Very Low (0-80C))	Natural Break	16.29
		Low (8-170C)		9.15
		Medium (17-23 0C)		30.62
		High (23-28 0C)		28.49
		Very High (28-43 0C)		15.45
	Chamoli	Very Low (-29 to -1.5 0C)	Natural Break	9.27
		Low (-1.5-5.80C)		30.70
		Medium (5.8-14.3 0C)		15.34

		High (14.3-22.10C)		20.15
		Very High (22.1-39.40C)		24.55

Table 6: Accuracy assessment result for LULC map of Tehri Garhwal

Classes	**Random points**	**Correct points**	**Accuracy (%)**
Water	10	10	100.00%
Barren land	7	6	85.71%
Agriculture	16	10	62.50%
Snow	17	13	76.47%
Very dense forest	17	15	88.24%
Moderately dense forest	32	29	90.63%
Open forest	24	19	79.17%
Scrub land	14	10	71.43%
Settlements	13	10	76.92%
Total	150	122	

Landslide susceptibility mapping

As per the methodology described in preceding section, remote sensing data and collateral data were manipulated in the GIS environment. Each parameter identified to have influence on landslide occurrence in the Tehri Garhwal district is evaluated, classified and ranked individually. Weights are calculated using AHP method and LSM of the Tehri Garhwal district is produced (Figure 19) by combining different weighted parameters using WLC method in GIS environment.

High rainfall in the hilly regions always increases the probability of landslides, therefore, highest rank score is given to the high rainfall (Biswakarma et al., 2020). Probability of landslide occurrence increases where the slope is steeper compared with gentler ones (Pham et al., 2020), Hence, high rank score is given to the steeper slopes while gentler slopes are given lower rank score. In case of Uttarakhand Himalayas, southern aspect receives excessive sun radiation and high rainfall is more vulnerable to landslides (Kumar and Anbalagan 2016). Additionally, presence of agricultural terraces on southwest facing slopes leads to more instability. In present study, highest rank score is given to the south facing slopes followed by West, East and North (Table 7).

Geology of the Tehri Garhwal has been given rank based on the study carried by Kumar and Anbalagan (2016) in the same study area where Jaunsar group of rocks is given lowest rank followed by Central Crystalline, Krol, Baliana, Garhwal. Highest rank is given to undifferentiated quaternary rocks because of its high weathering potential. Geology of Rudraprayag is classified into five classes viz. Central crystalline, Rautgara, Volcanics of Garhwal group, Granitoid of Amritpur, Almora, and Chamoli, Granitoid of Kedarnath and Champawat. Highest rank is given to Rautgara group and lowest rank is given to Granitoid of Kedarnath and Champawat based on their weathering potential. Similarly, Geology of Chamoli is classified into five classes such as Toli Granite, Baijnath, Quarternary, Sumna and Lagudarsi.

Similarly, Soil groups are also ranked according to its characteristics. For instance, Highest rank score was given to the type of rocks having severe erosion potential i.e. Lithic Udorthents followed by Typic Udorthents, Dystric Eutrochrepts, Lithic cryothents and Glacier (Table 7). High NDVI values represent dense vegetation cover which implies that there will be less probability of landslide occurrence (Senouci et al., 2021). Therefore, low class rank is given to the high NDVI values and high class rank is given to the low NDVI values (Table 7). Higher TWI values are given higher rank score because generally majority of landslides are observed close to higher TWI values (Wang et al., 2015; Li et al., 2021). Similarly, highest rank score is given to the minimum distance buffer from roads and drainage as majority of the landslides tends to occur in the close proximity of the roads and drainage (El Jazouli et al., 2019; Bahrami et al., 2021) (Table 7).

Table7: Distribution of rank score to different subclasses of factors

Parameters	**Classes (Tehri Garhwal)**	**Classes (Rudraprayag)**	**Classes (Chamoli)**	**Class score**
Rainfall	50.46-81.45 mm	1356- 1545 mm	881.7-1134.9mm	1
	81.45 - 123.08 mm	1545 - 1763 mm	1134.9-1253.8mm	2
	123.04-165.44 mm	1763 -1974 mm	1253.8-1376.6mm	3
	165.44-205.39 mm	1974-2131 mm	1376.6-1572.2 mm	4
	205.39-258.40mm	2131-2267 mm	1572.2-1859.9 mm	5
Slope	0 -14.620	0 -16.540	0 -15.730	1
	14.620- 22.330	16.540 -25.730	15.730 - 26.650	2
	22.330 -31.110	25.730 -34.620	26.650 - 36.930	3
	31.110 -39.820	34.620 -44.730	36.930 - 48.490	4

	39.820 - 79.33°	44.730 - 78.12°	48.490 - 81.88°	5
Aspect	North	North	North	1
	North East	North East	North East	2
	East	East	East	3
	South East	South East	South East	5
	South	South	South	5
	South West	South West	South West	5
	West	West	West	4
	Northwest	Northwest	Northwest	4
NDVI	-0.19-0.03	-.18-0.03	0.24-0.03	5
	0.03-0.12	0.03-0.11	0.03-0.05	4
	0.12-0.19	0.11-0.19	0.05-0.14	3
	0.19-0.26	0.19-0.26	0.14-0.24	2
	0.26-0.49	0.26-0.53	0.24-0.50	1
TWI	1.69-4.67	1.84-4.59	1.47 - 4.48	1
	4.67-5.96	4.59-5.94	4.48 - 5.88	2
	5.96-7.59	5.94-7.57	5.88- 7.57	3
	7.59-9.92	7.57-9.90	7.57 - 9.99	4
	9.92-18.21	9.90-19.87	9.99 - 20.21	5
	Jaunsar	Granitoid of Kedarnath and Champwat	Toli Granite	1
	Central Crystalline	Granitoid of Amritpur, Almora, Chamoli	Sumna	2
		Volcanics of Garhwal group		
	Krol/Baliana/Garhwal	Central Crystalline	Lagudarsi	3
	Sirmur=Dharamshala/ Tal	Agastmuni formation	Quaternary	4
	Newer Alluvium/Undifferentiat	Rautgara	Baijnath	5

	ed quarternary			
Soil	Dystric Eutrochrepts	Typic Udorthents	Typic Udorthents	3
	Typic Udorthents	Lithic Udorthents	Lithic Udorthents	4
	Lithic Udorthents	Lithic Cryothents	Lithic Cryothents	5
	Glacier	Dystric Eutrochrepts	Glaciers	1
	Lithic Cryothents	Typic Dystrochrepts	Typic Cryothents	2
Road Proximity	0-100m	0-100m	0-100m	5
	100-200m	100-200m	100-200m	4
	200-300m	200-300m	200-300m	3
	300-400m	300-400m	300-400m	2
	>400m	>400m	>400m	1
Drainage Density	0-0.57 km-1	0-73.2 km-1	17.52-75.58 km-1	1
	0.57-1.10 km-1	73.2-106.4km-1	75.58-101.70 km-1	2
	1.10-1.66 km-1	106.4-139.7km-1	101.70-120.52 km-1	3
	1.66-2.34 km-1	139.7-184.1km-1	120.52-141.62 km-1	4
	2.34-4.05 km-1	184.1-282.8km-1	141.62-202.58 km-1	5

In present study, AHP is used for calculation of weights for each landslide causative factors. AHP based matrix defining scores of the landslides causative factors, maximum eigen value, CR and CI for present study is given in Table (8). Highest weight is assigned to the aspect, slope followed by NDVI and geology.

Table 8(a) AHP scores of factors, weights, CR and Highest Eigen value for Tehri Garhwal

Factors	1	2	3	4	5	6	7	8	9	Normalized Eigen/Weight
Slope(1)	1									0.22
Aspect(2)	1.0	1								0.176
NDVI (3)	0.5	0.25	1							0.140
Soil (4)	0.5	0.46	0.33	1						0.126
Geology (5)	0.5	0.5	0.2	1.0	1					0.123

TWI (6)	0.33	0.5	0.65	0.5	0.5	1				0.108
Proximity To roads (7)	0.25	0.17	0.5	0.5	0.5	0.5	1			0.046
Proximity to Drainage (8)	0.25	0.5	0.25	0.33	0.25	0.2	0.5	1		0.034
Rainfall (9)	0.33	0.2	0.14	0.2	0.2	0.25	0.5	0.5	1	0.027

Table 8(b) AHP scores of factors, weights, CR and Highest Eigen value for Rudraprayag

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Normalized Eigen/Weight**
Aspect (1)	1									0.184
Soil (2)	0.5	1								0.181
Slope (3)	1	0.5	1							0.17
Drainage density (4)	0.5	0.33	0.5	1						0.097
TWI (5)	0.5	0.5	0.33	0.5	1					0.092
Road Proxiity (6)	0.33	0.33	0.25	0.5	0.5	1				0.058
Rainfall (7)	0.5	0.33	0.33	1	0.5	1	1			0.097
NDVI (8)	0.33	0.33	0.5	1	0.5	1	0.33	1		0.067
Geology (9)	0.33	1	0.5	0.33	0.5	0.5	0.2	0.33	1	0.054
CR= 0.086, CI= 0.124, Maximum Eigen value= 9.93										

The output LSM of Tehri Garhwal, Rudraprayag and Chamoli (Figure 19a-c) based on weighted Linear Combination (WLC) method classified the districts into five susceptible categories as Very low, Low, Medium, High and Very High. Percentage area in each class is calculated (Table 9).

Table 9 Classification of Landslide susceptibility and corresponding area in percentage

Landslide Susceptibility Classes	**Area in (%)**		
	Tehri Garhwal	Rudraprayag	Chamoli
Very Low	14.1	10.04	7.97
Low	23.4	23.56	21.52

Moderate	34.1	24.68	25.59
High	21.7	24.83	25.38
Very High	6.7	16.89	19.55

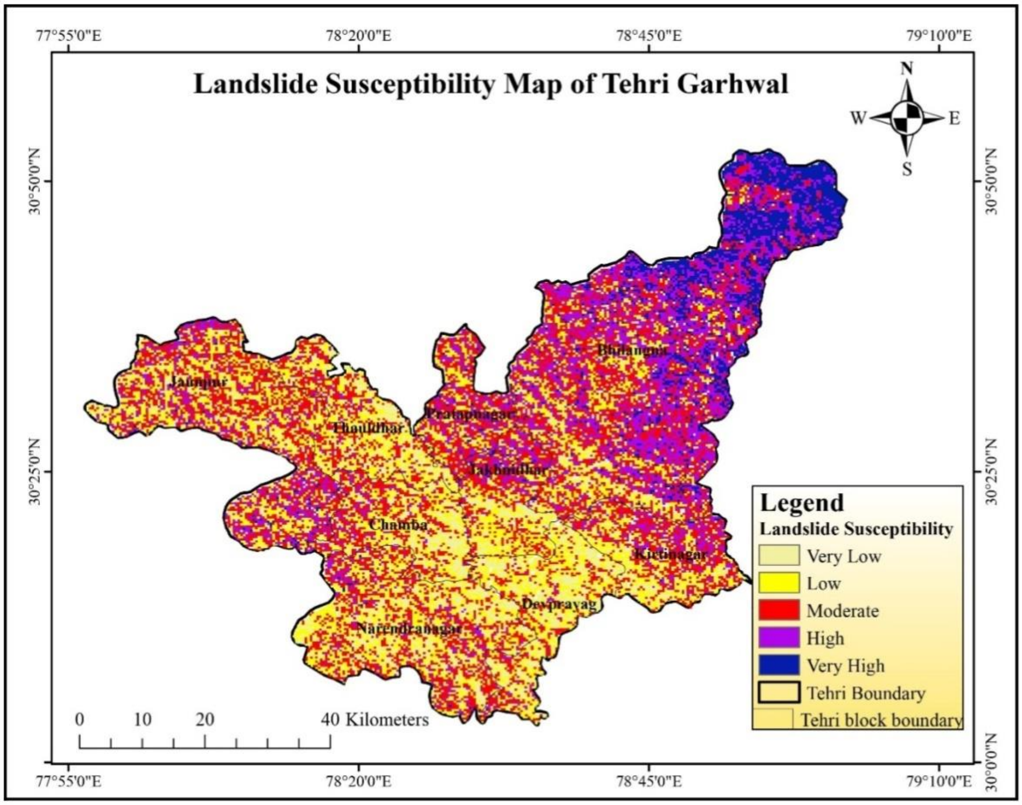


Figure 19 (a): Landslide Susceptibility Map of Tehri Garhwal

The Resultant landslide susceptibility map classified the Tehri Garhwal district into five classes ranging from very low to very high susceptibility.LSM of Tehri Garhwal indicates that 14.1% and 23.4% of the total district area is classified into very low and low landslide susceptibility while 34.1% area has moderate landslide susceptibility. 28.4% of the total district has high and very high landslide susceptibility. Bhilangana, Pratapnagar, Jakhnidhar and Kirtinagar blocks are found to have high and very high landslide susceptibility which is confirmed by field visits. LSM of Rudraprayag (Figure 20b) indicates that 10.04% and 23.56% of the total district area is classified into very lo and low landslide susceptibility, whereas 24.68% of the district's area is grouped under moderate class. Around 41.42% of the total area of Rudraprayag has high to very high landslide susceptibility. Areas near Ukhimath, Kedarnath and Agastmuni are found to have very high landslide susceptibility.

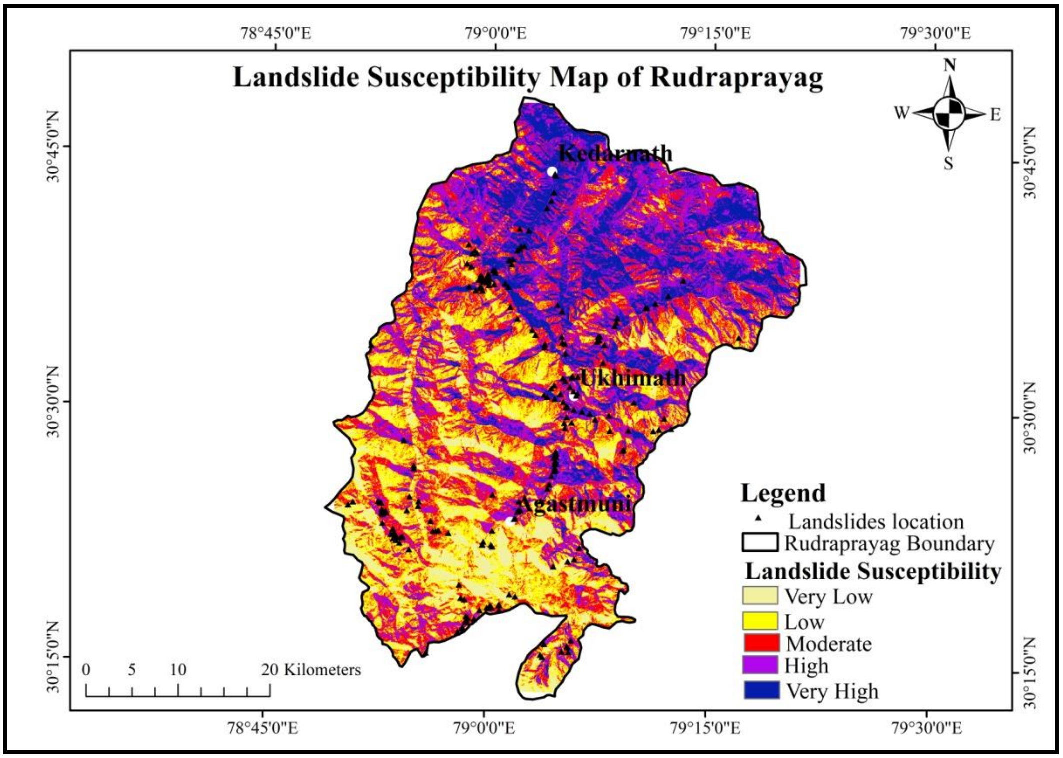


Figure 19 (b): Landslide Susceptibility Map of Rudraprayag

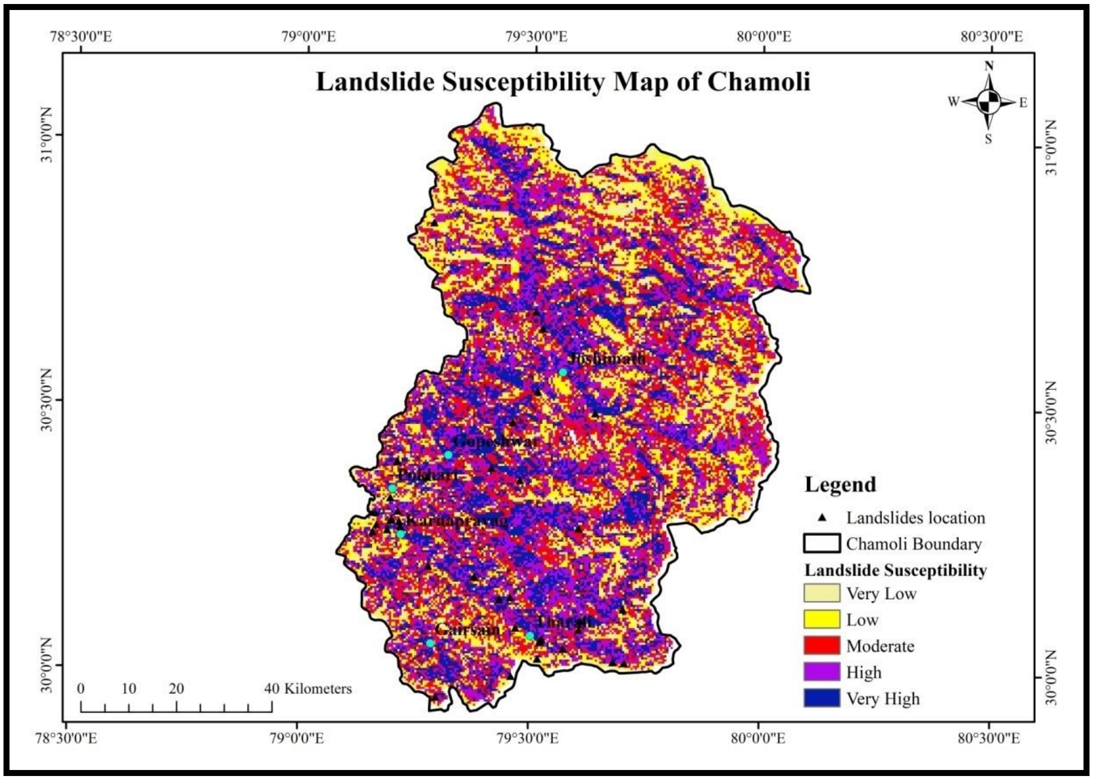


Figure 19 (c): Landslide Susceptibility Map of Chamoli

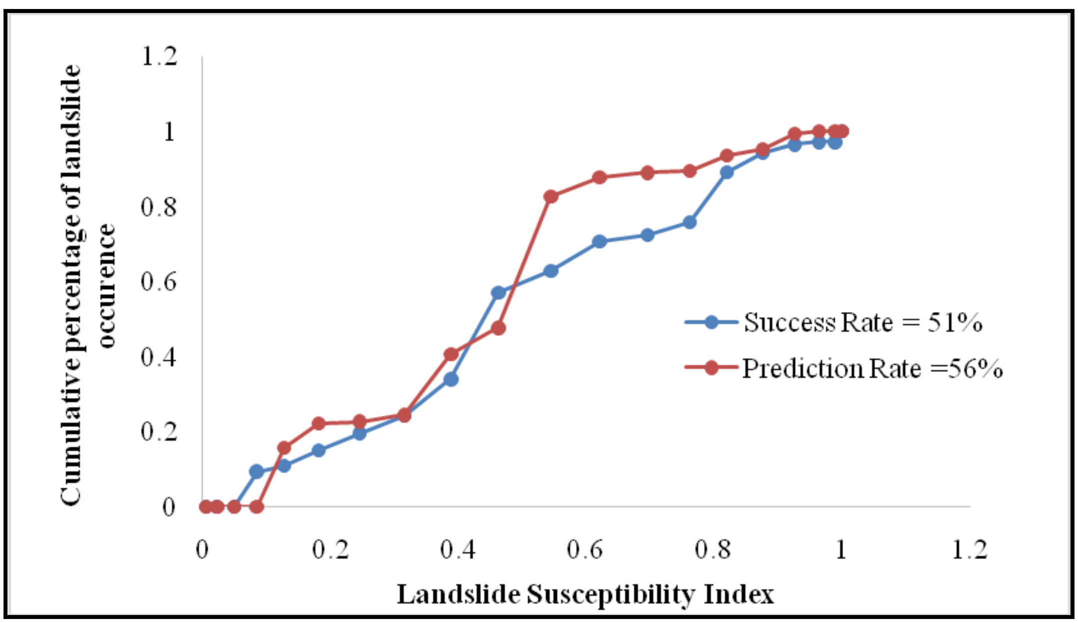


Figure 20: Success rate and prediction rate curve for landslide susceptibility model for Tehri Garhwal

For validation of LSM, AUC values under success rate curve (SRC) and prediction rate curve (PRC) is calculated. SRC demonstrates how the categorization matches with the model whereas PRC illustrates the model prediction accuracy. Landslide inventory is classified into two data sets i.e. training data set (70% locations) and prediction data set (30% locations). Training dataset is used for SRC whereas prediction dataset is utilized for PRC. The area ratio curve of success rate and prediction rate curve is 0.5129 and 0.5552 respectively (Figure 20) for Tehri Garhwal. The susceptibility map of Tehri Garhwal is validated using area under the ROC which shows 51% success rate and 56% prediction rate.

The accuracy of landslide susceptibility map is based on the location of past landslides. If all the previous landslides fall in the areas classified under high to very high susceptibility, then the accuracy or prediction rate increases dramatically (Mirdda et al., 2020). However, in current study area landslides have also occurred in the moderate and low susceptibility classes and accountable for moderate accuracy.

The resultant maps are useful for the policy makers and administrators in spatial planning and other developmental activities in the study districts. It is recommended to update the resultant maps with more causative factors like Land Use/ Land Cover and more geological information such as lineaments, folds and faults. To improve the accuracy of the LSM quantitative methods such as statistical and deterministic models can be applied and compared.

Forest fire susceptibility mapping

The analysis of forest fire susceptibility of the study districts is analyzed through AHP method considering ten parameters i.e. slope, aspect, drainage density, elevation, LULC, NDVI, LST, rainfall, road and settlements,

The slope is an indicator of the rate of change of elevation. The rapid spread of fires usually moved faster uphill than downhill (Mukharjee & Raj 2014). The steeper slope helped to spread fire because fuel was more dried on the upper slope than the lower slope. Therefore, high rating is given to the steep slopes comparative to the gentler slope. Aspect can be described as the direction of the maximum rate of change in elevation between each cell and its neighbors. An eastern part of the slope gets more sunlight early in the morning than a slope with a west aspect. Also, the southern part of the slope gets more sunlight in the northern hemisphere, so the temperature on the southern side was high and fuel gets dry easily. The southern aspect received more sunlight at a very high risk of forest fire. In present study, highest rank score is given to the south facing slopes followed by West, East and North (Table 10). The drainage density has influence in fire spread, that is, the chance of fire ignition is low wherever drainage density is low, and the probability to fire keeps on increasing as the drainage density increases. Therefore, high rank score is given to the class having low drainage density.

Usually, a decreasing trend in forest fires is apparent with rising elevation due to lower temperatures and higher humidity as opposed to the regions at a lower elevation (Rothermel RC, 1983). It was found that forest fire incidents are mostly very high in numbers in the lower and moderate elevation ranges, whereas there were fewer fire incidents at high elevations in the study area. This can be attributed to the high moisture content in vegetation and soil which made it unfavorable for ignition and spread of fire. Hence, high rank score is given to the low and medium elevation class whereas low rank score is given to the high and very high elevation class (Table 10).

LULC dynamics are mostly accelerated by human activities which caused many changes those affect various forests and environment ecosystem (Kumar et al., 2018). Many previous kinds of research have focused on the importance of land cover classes in evaluating the risk of a given area to fire events as it is related to fuel types and characteristics (Vadrevu et al., 2010; Szpakowski and Jensen, 2019). Most of the fire areas are caused due to the slash and burnt of forest areas for cultivation purposes and forests such as very dense forest, dense forest, and the open forest have fallen under very high-risk zone and given high rank score followed by agriculture, scrubland, settlements, water and snow cover (Table 10).

A higher NDVI value is indicative of dense vegetation, while lower NDVI value indicates sparse vegetation. The chance of forest fire is higher in areas with dense vegetation (Pradeep et al., 2022), therefore high rank score is given to the high NDVI values followed by medium and low NDVI values in the study area (Table 10).

Generally, rainfall affects both the moisture content of the fuel and the soil. The areas with high rainfall were fewer fire incidents due to the high moisture content of the fuel. The amount and time of rainfall played a crucial role in the physiological growth of vegetation and influenced the formation of forest fire (Pereira et al., 2005). In the present study, high rank score is given to the classes having low rainfall ranges whereas low score is given to the classes having high rainfall values (Table 10).

Land surface temperature played an important role in a forest fire. High temperature helped to the rising rate of evapotranspiration where the seasonal drying of fuel, such as needles, leaves, twigs, and dead trees, resulted in inappropriate conditions that were suitable for an explosion of fire (Lamat et al., 2021). The areas with low temperature are less susceptible to fire occurrences because of the moisture content present in fuel where the conditions are not very suitable for ignition of fire. In present study high rank score is given to the high LST whereas low rank score is allotted to class having low LST values (Table 10).

Forests located near settlements and roads are more prone to forest fires. The movement of people through forest roads can create intentional or unintentional fires (Veena et al., 2017). Accidental or unintentional fires occur mainly due to careless disposal of burning materials like cigarettes butts, match sticks by people. Intentional forest fires occur mainly for fire set to clear the forest path. Based on the literature review, the high score rank is assigned to closer proximity of settlement and roads (Table 10).

Table10: Distribution of rank score to different subclasses of factors

Parameters	**Classes (Tehri Garhwal)**	**Classes (Rudraprayag)**	**Classes (Chamoli)**	**Class score**
Rainfall	424.06-707.1mm	1356- 1545 mm	881.7-1134.9mm	5
	707.1 – 858 mm	1545 - 1763 mm	1134.9-1253.8mm	4
	858 -1018.4 mm	1763 -1974 mm	1253.8-1376.6mm	3
	1018.4 -1306.02 mm	1974-2131 mm	1376.6-1572.2 mm	2
	1306.02 -1626.9 mm	2131-2267 mm	1572.2-1859.9 mm	1
Slope	0 -14.620	0 -16.540	0 -15.730	5
	14.620- 22.330	16.540 -25.730	15.730 - 26.650	4
	22.330 -31.110	25.730 -34.620	26.650 - 36.930	3
	31.110 -39.820	34.620 -44.730	36.930 - 48.490	2
	39.820 - 79.33	44.730 - 78.12	48.490 - 81.88	1
Aspect	North	North	North	1

	North East	North East	North East	2
	East	East	East	3
	South East	South East	South East	5
	South	South	South	5
	South West	South West	South West	5
	West	West	West	4
	Northwest	Northwest	Northwest	4
Drainage density	0-0.57 km-1	0-73.2 km-1	17.52-75.58 km-1	1
	0.57-1.10 km-1	73.2-106.4km-1	75.58-101.70 km-1	2
	1.10-1.66 km-1	106.4-139.7km-1	101.70-120.52 km-1	3
	1.66-2.34 km-1	139.7-184.1km-1	120.52-141.62 km-1	4
	2.34-4.05 km-1	184.1-282.8km-1	141.62-202.58 km-1	5
Elevation	330- 1272m	573 - 1667m	683 -2056m	5
	1272 -1888m	1667 -2483m	2056- 3062m	4
	1888 - 2721m	2483 - 3421m	3062 - 4163m	3
	2721m - 4075m	3421 - 4479m	4163 - 5171m	2
	4075m - 6622m	4479 -6943m	5171 - 7811m	1
LULC	Water	Water	Water	1
	Barren land	Bare ground	Bare ground	1
	Agriculture	Crops	Crops	4
	Snow	Snow	Snow	1
	Forest	Trees	Trees	5
	Settlements	Settlements	Settlements	2
	Scrubland	Scrub/shrubs	Scrub/shrubs	3
NDVI	-0.19-0.03	-.18-0.03	0.24-0.03	1
	0.03-0.12	0.03-0.11	0.03-0.05	2
	0.12-0.19	0.11-0.19	0.05-0.14	3

	0.19-0.26	0.19-0.26	0.14-0.24	4
	0.26-0.49	0.26-0.53	0.24-0.50	5
Road Proximity	0-100m	0-100m	0-100m	5
	100-200m	100-200m	100-200m	4
	200-300m	200-300m	200-300m	3
	300-400m	300-400m	300-400m	2
	>400m	>400m	>400m	1
Settlements Proximity	0-100m	0-100m	0-100m	5
	100-200m	100-200m	100-200m	4
	200-300m	200-300m	200-300m	3
	300-400m	300-400m	300-400m	2
	>400m	>400m	>400m	1
Land surface temperature	0.19-0.030C	0-80C	-29 to -1.5 0C	1
	0.03-0.12 0C	8-170C	-1.5-5.80C	2
	0.12-0.19 0C	17-23 0C	5.8-14.3 0C	3
	0.19-0.26 0C	23-28 0C	14.3-22.10C	4
	0.26-0.480C	28-43 0C	22.1-39.40C	5

In present study, AHP is used for calculation of weights for each forest fire causative factors. AHP based matrix defining scores of the forest fire causative factors, maximum eigen value, CR and CI for each district under study area is given in Table (11a to 11c).

Table 11a AHP scores of factors, weights, CR and Highest Eigen value for Tehri Garhwal

Factors	1	2	3	4	5	6	7	8	9	10	Normalized Eigen/Weight
Elevation (1)	1	1	3	1	1	3	1	3	1	3	0.15
LULC(2)	1	1	1	1	3	1	1	1	3	1	0.134
Drainage density(3)	0.333	1	1	1	1	3	1	3	1	1	0.111
NDVI (4)	1	1	1	1	1	1	3	1	3	1	0.109
Roads (5)	1	0.333	1	1	1	1	3	1	1	1	0.086
Slope (6)	0.333	1	0.333	1	1	1	1	3	1	3	0.104
LST(7)	1	1	1	0.333	0.333	1	1	1	3	1	0.093
Aspect (8)	0.333	1	0.333	1	1	0.333	1	1	1	0.333	0.075
Settlements (9)	1	0.333	1	0.333	1	1	0.333	1	1	1	0.069
Rainfall (10)	1	1	1	1	1	0.333		1	1	1	0.07
CR= 0.099 , CI= 0.147 Maximum Eigen value= 11.31											

Table 11b AHP scores of factors, weights, CR and Highest Eigen value for Rudraprayag

Factors	1	2	3	4	5	6	7	8	9	10	Normalized Eigen/Weight
Elevation (1)	1	1	3	3	1	3	1	3	1	3	0.165
LULC(2)	1	1	1	1	3	1	3	1	3	1	0.136
Drainage density(3)	0.333	1	1	1	1	3	1	3	1	1	0.104
NDVI (4)	0.333	1	1	1	1	3	1	3	1	1	0.104
Roads (5)	1	0.333	1	1	1	1	3	1	1	1	0.086
Slope (6)	0.333	1	0.333	0.333	1	1	1	3	1	1	0.104
LST(7)	1	0.333	1	1	0.333	1	1	1	3	1	0.089
Aspect (8)	0.333	1	0.333	0.333	1	0.333	1	1	1	3	0.077
Settlements (9)	1	0.333	1	1	1	1	0.333	1	1	1	0.076
Rainfall (10)	0.333	1	1	1	1	1	1	0.333	1	1	0.075
CR= 0.099 , CI=0.147 Maximum Eigen value= 11.31											

Table 11c AHP scores of factors, weights, CR and Highest Eigen value for Chamoli

Factors	1	2	3	4	5	6	7	8	9	10	Normalized Eigen/Weight
Elevation	1	1	3	1	1	3	1	3	1	1	0.135
LULC	1	1	1	1	3	1	1	1	3	1	0.12
Drainage Density	0.333	1	1	1	1	3	1	3	1	1	0.108
NDVI	1	1	1	1	1	1	3	1	3	1	0.117
Road	1	0.333	1	1	1	1	3	1	1	1	0.097
Slope	0.333	1	0.333	1	1	1	1	3	1	3	0.104
LST	1	1	1	0.333	0.333	1	1	1	3	1	0.089
Aspect	0.333	1	0.333	1	1	0.333	1	1	1	0.333	0.064
Settlement	1	0.333	1	0.333	1	1	0.333	1	1	1	0.069
Rainfall	1	1	1	1	1	0.333	1	3	1	1	0.096
CR= 0.099 , CI= 0.147 Maximum Eigen value= 11.31											

The output forest fire susceptibility map of Tehri Garhwal (Figure 21a), Rudraprayag (Figure 21b) and Chamoli (Figure 21c) based on weighted Linear Combination (WLC) method classified the districts into five susceptible categories as Very low, Low, Medium, High and Very High. Percentage area in each class is calculated (Table 12).

Table 12 Classification of forest fire susceptibility and corresponding area in percentage

Forest fire susceptibility class	Area in %		
	Tehri Garhwal	Rudraprayag	Chamoli
Very low	7.85	10.55	11.60
Low	13.76	24.11	21.11
Moderate	29.86	30.34	26.01
High	31.47	23.50	25.49
Very High	17.05	11.49	15.78

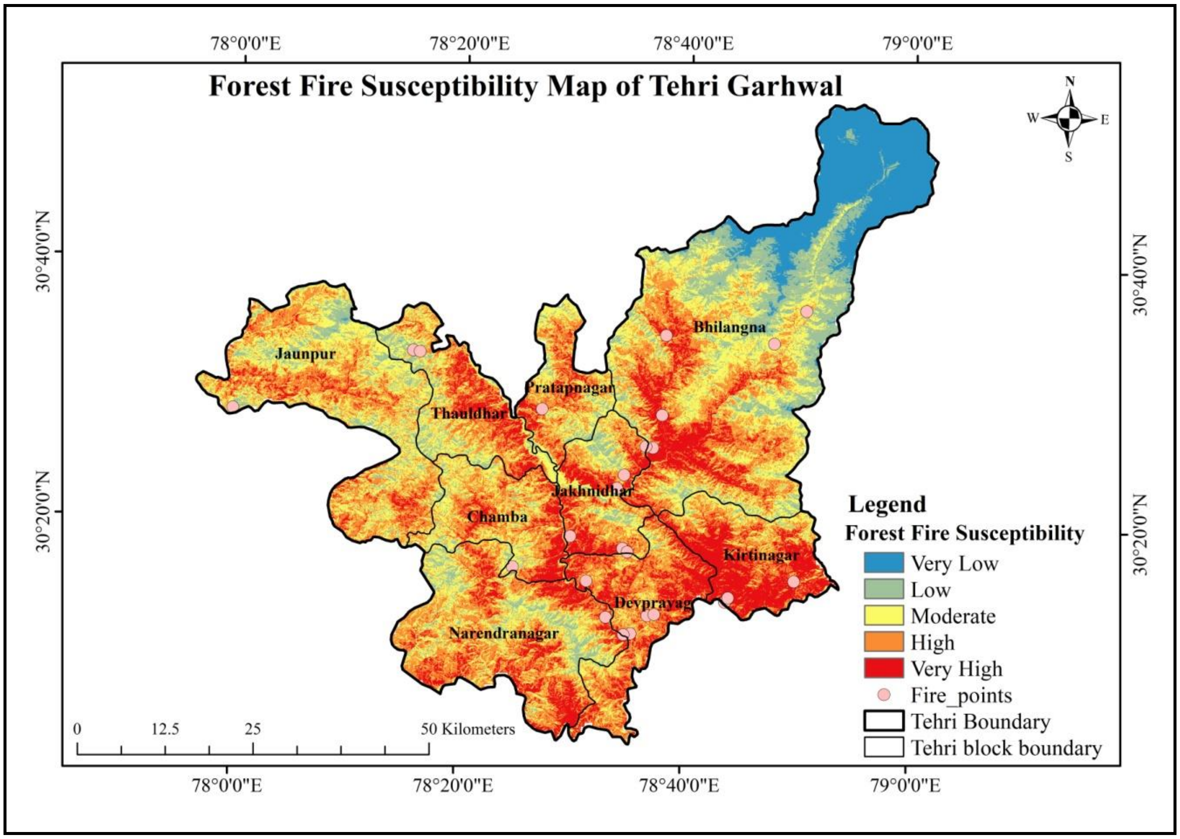


Figure 21a: Forest fire Susceptibility Map of Tehri Garhwal

Forest fire susceptibility map of Tehri Garhwal indicates that 7.58% and 13.76% of the total district area is classified into very low and low forest fire susceptibility while 29.86 % of the total area has moderate forest fire susceptibility. 31.47 % and 17.05 % of the total district has high and very high forest fire susceptibility. Bhilangna, Jaunpur and Kirtinagar, Chamba and Jakhnidhar blocks are found to be more susceptible to forest fire, which is confirmed by the field visits and secondary sources.

Forest fire susceptibility map of Rudraprayag shows that 10.55% and 24.11 of the district's area fall under very low and low susceptibility to forest fires respectively. 30.34% of the area is classified under moderate fire susceptibility, whereas 23.50% and 11.49% of the district's area falls under high and very high forest fire susceptibility. The potential areas for forest fires are concentrated mostly in the Rudraprayag block of the district. In addition, very high fire susceptibility areas are found mostly in the areas having high land surface temperature in the southern area of the study area

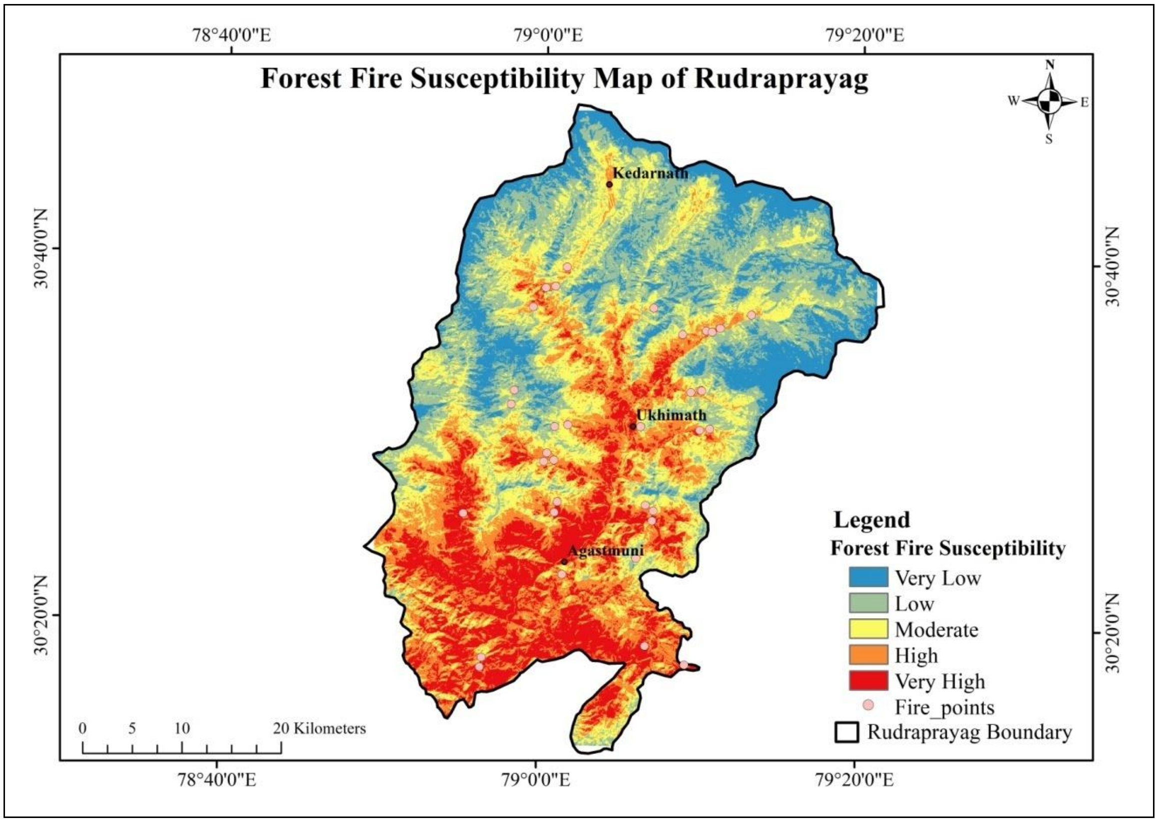


Figure 21b: Forest fire Susceptibility Map of Rudraprayag

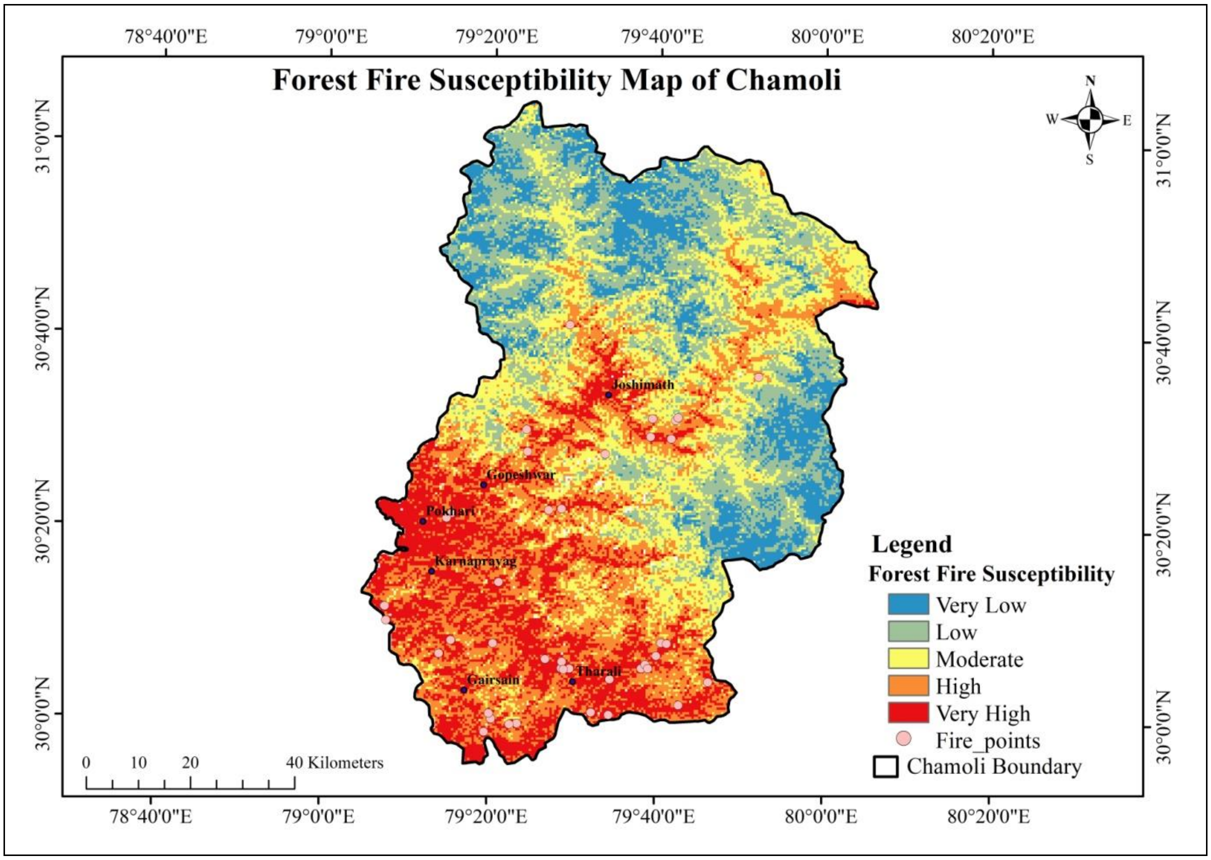


Figure 21c: Forest fire Susceptibility Map of Chamoli

Forest fire susceptibility map of Chamoli district shows that 11.6% and 21.11% of the district's area fall under very low and low susceptibility to forest fires respectively. 26.01% of the area is classified under moderate fire susceptibility, whereas 25.49% and 15.78% of the district's area falls under high and very high forest fire susceptibility. The potential areas for forest fires are concentrated mostly in the Tharali, Gairsain, Karanprayag and Pokhari blocks of the district. In addition, very high fire susceptibility areas are found mostly in the areas having high land surface temperature in the southern part of the Chamoli district.

The validation of the forest fire susceptibility zones are verified by the fire points of MODIS and SNPP sensor acquired from Forest fire alert system 3.0 of Forest Survey of India (FSI) (www.fsiforestfire.gov.in). Most of the fire points overlaid on the maps of each district under study area are seen as high or very high-risk zone (Figure 21a-21c).

Flash flood susceptibility mapping

To prepare the flash flood susceptibility maps of the study area, ten factors are considered which includes elevation, slope, rainfall, drainage density, soil, geology, geomorphology, LULC, TWI and NDVI.

Many factors influence catchment hydrologic characteristics, which ultimately influence surface runoff production. It governs overland movement, penetration, and the length of subsurface flow. The combination of slope angles defines the slope shape and its relationship with various other parameters such as lithology, composition, soil type, and drainage. The slope classes with less value were given a higher level, while the class with the maximum value was classified as lower due to its comparatively high runoff. The tendency of water accumulation is from higher to lower elevations. Elevation data demonstrates how the height of the ground varies across a region. Because of the simultaneous accumulation of rainwater, lower elevations are more vulnerable to flash floods. The higher elevations are given low value as compared to lower elevations where water accumulation tendency is high (Table 13a-13c). Flood susceptibility and heavy rainfall are both positively correlated with flood occurrences. High rainfall triggers flash flooding therefore higher values are assigned to the high and very high rainfall classes (Table 13a-13c).

Drainage density is considered an essential element of flooding. The higher likelihood of flooding is strongly linked to higher drainage density as it points toward a greater surface run-off (Das et al., 2019). In this study, the drainage density has a direct relationship with flooding. The probability of flooding increases with an increase in drainage density and decreases with a decrease in drainage density. During the research, high weightages are allocated to high drainage density areas, and lower weights were allocated to areas with low drainage. Land use/cover is another important variable in flood mapping. It reflects the land's current use, pattern, and types of use, and thus its importance for soil stability and infiltration. Forest cover and vegetation cover, whether permanent grassland or another crop cover, has a significant impact on the soil's ability to store water. Flooding from rainwater is much more common on bare fields than on those with adequate forest cover and crop cover. In present study, high value is given to water bodies, while a lower value is given to different forest types. The NDVI is another important causative factor of flooding. Khosravi et al. (2016) stated that the negative values show water and the positive values show vegetation so, NDVI has negative relationship with flooding: higher NDVI values indicate lower probability of flood and lower NDVI values indicate higher flood probability. TWI has a direct positive relationship with flooding (Das et al., 2019). The higher TWI class refers to higher chances of flooding (Tehrani et al., 2015). Hence, high weightage is given to high TWI values which low weightage is given to the low TWI values (Table 13a-13c).

Pair wise comparison matrix, consistency ratio and normalized weights of different sub-classes of causative factor layers for the assessment of flash flood susceptibility for the study area is given in Table 13a-13c. AHP based matrix defining scores of the flash flood causative factors, maximum eigen value, CR and CI for each district under study area is given in Table (14a to 14c).

The flash flood susceptibility map of Tehri Garhwal (Figure 22a), Rudraprayag (Figure 22b) and Chamoli (Figure 22c) are prepared by the AHP method. After calculating the final weights of all parameters, it was converted to raster format and summed up using a raster calculator to demarcate the flash flood susceptible zones in ArcGIS software.

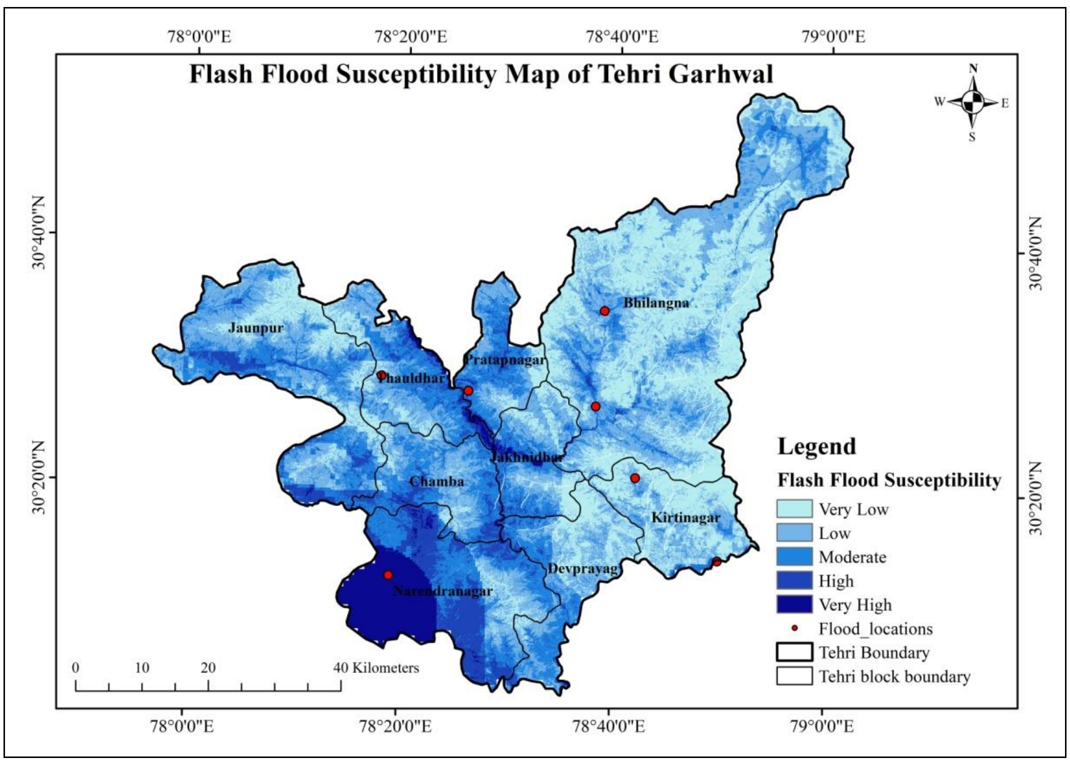


Figure 22a: Flash flood susceptibility map of Tehri Garhwal

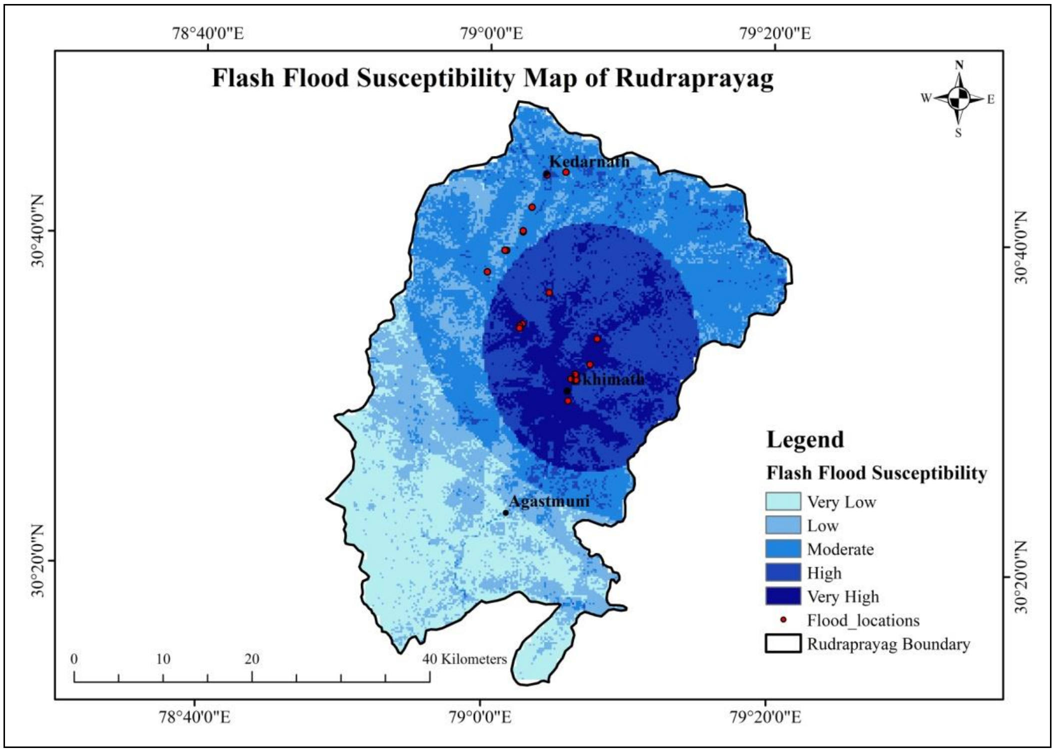


Figure 23b: Flash flood susceptibility map of Rudraprayag

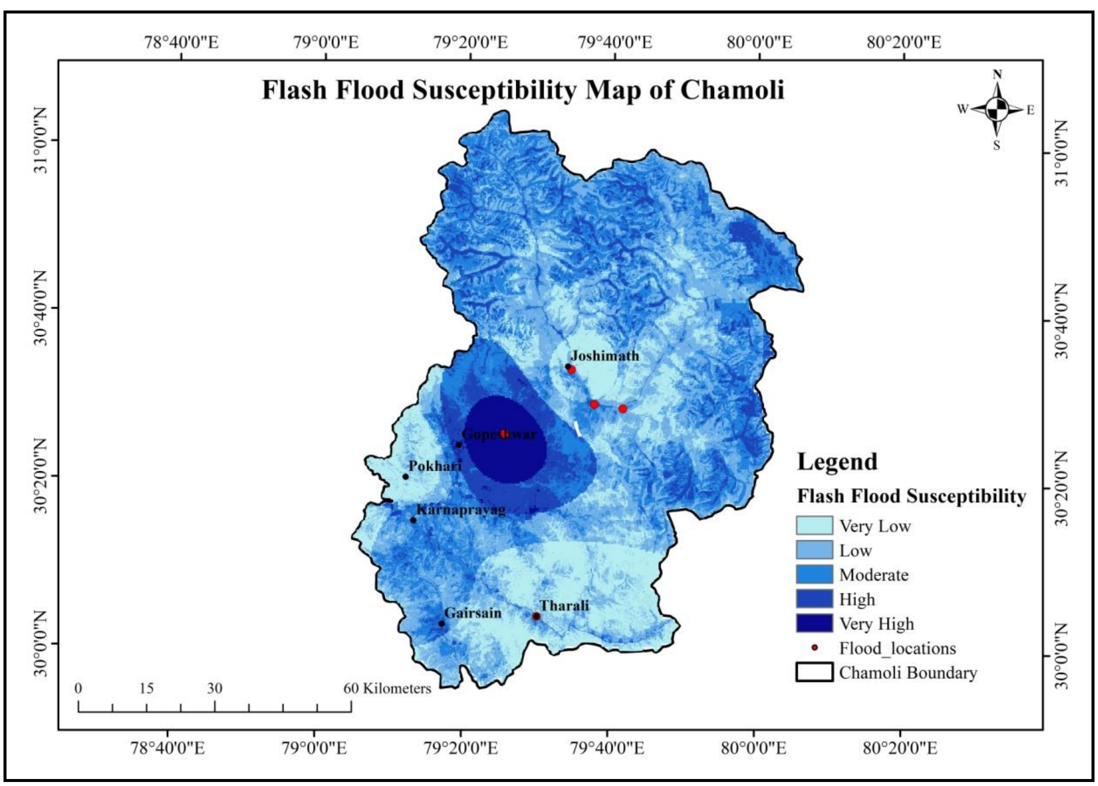


Figure 23c: Flash flood susceptibility map of Chamoli

Table 13a Pairwise comparison matrix, consistency ratio and final weights of different sub classes of thematic layer for assessment of flash flood susceptibility in Tehri Garhwal.

Causative Factors	Pair-wise comparison matrix									Normalized Weights	Consistency Ratio
Drainage Density											
0 - 74.29	1	0.5	0.333	0.25	0.2					0.062	
74.29 - 107.55	2	1	0.5	0.333	0.25					0.097	
107.55- 140.82	3	2	1	0.5	0.333					0.160	0.015
140.82- 185.18	4	3	2	1	0.5					0.262	
185.18 - 282.76	5	4	3	2	1					0.418	
Rainfall											
424.06-707.1	1	0.5	0.333	0.25	0.167					0.058	
707.1 – 858	2	1	0.5	0.333	0.2					0.091	
858 -1018.4	3	2	1	0.5	0.333					0.156	0.010
1018.4 -1306.02	4	3	2	1	0.5					0.256	
1306.02 -1626.9	6	5	3	2	1					0.440	
Elevation											
330- 1272	1	3	5	7	9					0.516	0.043
1272 -1888	0.333	1	3	5	7					0.263	
1888 - 2721	0.2	0.333	1	2	5					0.118	
2721m - 4075	0.143	0.2	0.5	1	3					0.068	

4075m - 6622	0.111	0.143	0.2	0.333	1					0.034	
Slope											
0 -14.62^0	1	3	5	7	9					0.491	0.089
14.62^0- 22.33^0	0.333	1	5	7	9					0.313	
22.33^0 -31.11^0	0.2	0.2	1	2	7					0.109	
31.11^0 -39.82^0	0.143	0.143	0.5	1	3					0.058	
39.82^0 - 79.33°	0.111	0.111	0.143	0.333	1					0.028	
NDVI											
-0.19-0.03	1	3	5	7	9					0.516	0.043
0.03-0.12	0.333	1	3	5	7					0.263	
0.12-0.19	0.2	0.333	1	2	5					0.118	
0.19-0.26	0.143	0.2	0.5	1	3					0.068	
0.26-0.49	0.111	0.143	0.2	0.333	1					0.034	
TWI											
1.69 - 4.67	1	0.5	0.333	0.25	0.167					0.058	
4.67 - 5.95	2	1	0.5	0.333	0.2					0.090	
5.95 - 7.56	3	2	1	0.5	0.333					0.156	0.010
7.56 - 9.89	4	3	2	1	0.5					0.255	
9.89- 18.21	6	5	3	2	1					0.440	
Geomorphology											
Mass Wasting	1	0.2	0.143	0.111	0.5	0.333				0.030	0.03
Hills and Valleys	5	1	0.333	0.143	3	3				0.121	

Alluvial	7	3	1	0.333	5	5				0.245	
River	9	7	3	1	6	7				0.489	
Glascial	2	0.333	0.2	0.167	1	0.5				0.049	
Snow cover	3	0.333	0.2	0.143	2	1				0.065	
Lithology											
S	1	2	3	4	5	7				0.389	0.034
M	0.5	1	2	3	4	5				0.249	
I	0.333	0.5	1	2	3	4				0.159	
SI	0.25	0.333	0.5	1	2	3				0.100	
SM	0.2	0.25	0.333	0.5	1	1				0.057	
SMI	0.143	0.2	0.25	0.333	1	1				0.046	
LULC											
Water	1	2	3	4	5	6	7	8	9	0.319	0.091
Snow	0.5	1	2	2	3	4	5	6	7	0.194	
Bare land	0.333	0.5	1	2	3	4	5	6	7	0.161	
Agriculture	0.25	0.5	0.5	1	2	3	4	5	6	0.115	
Bult-up	0.2	0.333	0.333	0.5	1	2	3	4	5	0.078	
Scrub	0.167	0.25	0.25	0.333	0.5	1	2	3	4	0.053	
Open Forest	0.143	0.2	0.2	0.25	0.333	0.5	1	1	2	0.032	
Moderate Forest	0.125	0.167	0.167	0.2	0.25	0.333	1	1	2	0.029	
Dense Forest	0.111	0.143	0.143	0.167	0.2	0.25	0.5	0.5	1	0.019	
Soil											

Fluvial Valley	1	1	3	4	5					0.378	
Side Slope	1	1	0.5	3	4					0.235	
Mountain and Valley Glacier	0.333	2	1	3	3					0.242	0.056
Cliffs	0.25	0.333	0.333	1	1					0.0757	
Ridge Top	0.2	0.25	0.333	1	1					0.068	

Table 13b Pairwise comparison matrix, consistency ratio and final weights of different features of thematic layer for assessment of flash flood susceptibility in Rudraprayag.

Causative Factors and sub classes	Pair-wise comparison matrix								Normalized Weights	Consistency Ratio
Drainage Density										
0-73.2	1	0.5	0.333	0.25	0.2				0.061767	
73.2-106.4	2	1	0.5	0.333	0.25				0.097254	
106.4-139.7	3	2	1	0.5	0.333				0.159923	0.015135
139.7-184.1	4	3	2	1	0.5				0.262518	
184.1-282.8	5	4	3	2	1				0.418539	
Rainfall										
1356- 1545	1	0.5	0.333	0.25	0.167				0.057955	
1545 - 1763	2	1	0.5	0.333	0.2				0.090697	
1763 -1974	3	2	1	0.5	0.333				0.15565	0.010282
1974-2131	4	3	2	1	0.5				0.255828	

2131-2267	6	5	3	2	1				0.43987	
Elevation										
573 - 1667	1	3	5	7	9				0.51606	0.043
1667 -2483	0.333	1	3	5	7				0.263488	
2483 - 3421	0.2	0.333	1	2	5				0.118358	
3421 - 4479	0.143	0.2	0.5	1	3				0.068372	
4479 -6943	0.111	0.143	0.2	0.333	1				0.033722	
Slope										
0 -16.54	1	3	5	7	9				0.49106	0.089
16.54-25.73	0.333	1	5	7	9				0.313454	
25.73 -34.62	0.2	0.2	1	2	7				0.108859	
34.62 -44.73	0.143	0.143	0.5	1	3				0.058203	
44.73- 78.12	0.111	0.111	0.143	0.333	1				0.028424	
NDVI										
-.18-0.03	1	3	5	7	9				0.51606	0.043
0.03-0.11	0.333	1	3	5	7				0.263488	
0.11-0.19	0.2	0.333	1	2	5				0.118358	
0.19-0.26	0.143	0.2	0.5	1	3				0.068372	
0.26-0.53	0.111	0.143	0.2	0.333	1				0.033722	
TWI										
1.47 - 4.48	1	0.5	0.333	0.25	0.167				0.057955	
4.48 - 5.88	2	1	0.5	0.333	0.2				0.090697	

5.88- 7.57	3	2	1	0.5	0.333				0.15565	0.010282
7.57 - 9.99	4	3	2	1	0.5				0.255828	
9.99 - 20.21	6	5	3	2	1				0.43987	
Geomorphology										
Mass Wasting	1	0.2	0.143	0.111	0.5	0.333			0.030005	0.052
Hills and Valleys	5	1	0.333	0.143	3	3			0.121047	
Alluvial	7	3	1	0.333	5	5			0.24549	
River	9	7	3	1	6	7			0.488789	
Glaciers	2	0.333	0.2	0.167	1	0.5			0.049409	
Snow cover	3	0.333	0.2	0.143	2	1			0.065259	
Lithology										
M	1	2	3	4	5	7			0.388829	0.06
MI	0.5	1	2	3	4	5			0.249186	
I	0.333	0.5	1	2	3	4			0.158784	
SM	0.25	0.333	0.5	1	2	3			0.100327	
SMI	0.2	0.25	0.333	0.5	1	1			0.056735	
S	0.143	0.2	0.25	0.333	1	1			0.046139	
LULC										
Water	1	2	4	4	5	6	7	8	0.341812	0.05217
Snow	0.5	1	2	3	4	4	5	5	0.212927	
Grass	0.25	0.5	1	2	3	4	4	4	0.142652	
Built Area Human made	0.25	0.333	0.5	1	3	4	5	6	0.125601	

structures										
crops	0.2	0.25	0.333	0.333	1	3	4	5	0.078847	
scrub	0.167	0.25	0.25	0.25	0.333	1	1	2	0.038684	
Bare ground	0.143	0.2	0.25	0.2	0.25	1	1	1	0.031709	
Trees	0.125	0.2	0.25	0.167	0.2	0.5	1	1	0.027768	
Soil										
Soils on Fluvial Valley	1	3	6	9					0.618593	0.04
Soils on Side slopes	0.333	1	2	3					0.206198	
Soils on cliffs	0.167	0.5	1	2					0.111093	
Soils on sumit and ridge tops	0.111	0.333	0.5	1					0.064116	

Table 13c Pair wise comparison matrix, consistency ratio and final weights of different features of thematic layer for assessment of flash flood susceptibility in Chamoli.

Causative Factors and Class within Each Factor	**Pair-wise comparison matrix**								**Normalized Weights**	**Consistency Ratio**
Drainage Density										
17.52-75.58	1	0.5	0.333	0.25	0.2				0.062	
75.58-101.70	2	1	0.5	0.333	0.25				0.097	
101.70-120.52	3	2	1	0.5	0.333				0.160	0.015
120.52-141.62	4	3	2	1	0.5				0.263	
141.62-202.58	5	4	3	2	1				0.419	

Rainfall										
881.7-1134.9	1	0.5	0.333	0.25	0.167				0.058	
1134.9-1253.8	2	1	0.5	0.333	0.2				0.091	
1253.8-1376.6	3	2	1	0.5	0.333				0.156	0.010
1376.6-1572.2	4	3	2	1	0.5				0.256	
1572.2-1859.9	6	5	3	2	1				0.440	
Elevation										
683 -2056	1	3	5	7	9				0.516	0.043
2056- 3062	0.333	1	3	5	7				0.263	
3062 - 4163	0.2	0.333	1	2	5				0.118	
4163 - 5171	0.143	0.2	0.5	1	3				0.068	
5171 - 7811	0.111	0.143	0.2	0.333	1				0.034	
Slope										
0 -15.73	1	3	5	7	9				0.491	0.089
15.73- 26.65	0.333	1	5	7	9				0.313	
26.65- 36.93	0.2	0.2	1	2	7				0.109	
36.93- 48.49	0.143	0.143	0.5	1	3				0.058	
48.49 - 81.88	0.111	0.111	0.142857	0.333	1				0.028	
NDVI										
0.24-0.03	1	3	5	7	9				0.516	0.043
0.03-0.05	0.333	1	3	5	7				0.263	
0.05-0.14	0.2	0.333	1	2	5				0.118	

0.14-0.24	0.143	0.2	0.5	1	3				0.068	
0.24-0.50	0.111	0.143	0.2	0.333	1				0.034	
TWI										
1.47 - 4.48	1	0.5	0.333	0.25	0.167				0.06	
4.48 - 5.88	2	1	0.5	0.333	0.2				0.09	
5.88 - 7.57	3	2	1	0.5	0.333				0.16	0.010
7.57 - 9.99	4	3	2	1	0.5				0.26	
9.99 - 20.21	6	5	3	2	1				0.44	
Geomorphology										
Fluvial Origin	1	2	3	7	0.25	4	4		0.202	
Structural origin highly dissected hills and valleys	0.5	1	2	3	0.2	3	3		0.122	
Structural origin moderately dissected hills and valleys	0.333	0.5	1	2	0.167	2	2		0.077	
Terraces	0.143	0.333	0.5	1	0.143	1	1		0.043	0.059
Water body	4	5	6	7	1	7	7		0.451	
Point bars	0.25	0.333	0.5	1	0.143	1	0.2		0.039	
Structural Origin low dissected hills and valleys/hanging valley/glacier valley	0.25	0.333	0.5	1	0.143	5	1		0.066	
Lithology										
S	1	7	7	3	4				0.430	
M	0.143	1	1	0.5	0.333				0.052	

I	0.143	1	1	0.5	0.333				0.046	0.037
SI	0.333	2	2	1	0.5				0.091	
SM	0.25	3	3	2	1				0.152	
SMI	0.2	4	4	2	0.5				0.144	
U	0.2	1	2	1	1				0.086	
LULC										
Water	1	2	4	4	5	6	7	8	0.342	0.052
Snow	0.5	1	2	3	4	4	5	5	0.213	
bare ground	0.25	0.5	1	2	3	4	4	4	0.143	
Built Area Human made structures	0.25	0.333	0.5	1	3	4	5	6	0.126	
crops	0.2	0.25	0.333	0.333	1	3	4	5	0.079	
scrub	0.167	0.25	0.25	0.25	0.333	1	1	2	0.039	
grass	0.143	0.2	0.25	0.2	0.25	1	1	1	0.032	
Trees	0.125	0.2	0.25	0.167	0.2	0.5	1	1	0.028	
Soil										
Soils on Fluvial Valley	1	2	3	4	5	6			0.377	
Soils on Mountane and Valley Glacier	0.5	1	2	3	4	5			0.247	
Upper glaciofluvial valley	0.333	0.5	1	2	3	4			0.157	0.042
Soils on Side slopes	0.25	0.333	0.5	1	3	4			0.115	
Soils on cliffs	0.2	0.25	0.333	0.333	1	3			0.065	
Soils on sumit and ridge tops	0.167	0.2	0.25	0.25	0.333	1			0.038	

Table 14a AHP scores of factors, weights, and CR for Tehri Garhwal

Factors	Elevation	Slope	Rainfall	Drainage Density	Soil	Geology	Geomorphology	LULC	TWI	NDVI	Priority (%)	CR
Elevation	1	1	0.111	0.333	5	0.5	1	0.2	3	4	0.058717	
Slope	1	1	0.111	1	1	1	1	0.333	2	3	0.052313	
Rainfall	9	9	1.000	9	9	9	9	3	9	9	0.414712	
Drainage Density	3	1	0.111	1	4	0.5	4	0.2	1	5	0.075874	
Soil	0.2	1	0.111	0.25	1	0.2	1	0.250	2	3	0.034889	
Lithology	2	1	0.111	2	5	1	3	0.333	3	7	0.093019	
Geomorphology	1	1	0.111	0.25	1	0.333	1	0.2	1	4	0.03766	
LULC	5	3	0.333	5	4	3	5	1	4	6	0.180155	
TWI	0.333	0.5	0.111	1	0.5	0.333	1	0.25	1	4	0.03614	0.082

											4	
NDVI	0.25	0.333	0.111	0.2	0.333	0.143	0.25	0.167	0.25	1	0.016518	

Table 14b AHP scores of factors, weights, and CR for Rudraprayag

Factors	**Elevation**	**Slope**	**Rainfall**	**Drainage Density**	**Soil**	**Geology**	**Geomorphology**	**LULC**	**TWI**	**NDVI**	**Priority (%)**	**CR**
Elevation	1	1	0.111	0.333	5	0.5	1	0.2	3	4	0.058717	
Slope	1	1	0.111	1	1	1	1	0.333	2	3	0.052313	
Rainfall	9	9	1.000	9	9	9	9	3	9	9	0.414712	
Drainage Density	3	1	0.111	1	4	0.5	4	0.2	1	5	0.075874	
Soil	0.2	1	0.111	0.25	1	0.2	1	0.25	2	3	0.034889	
Lithology	2	1	0.111	2	5	1	3	0.333	3	7	0.093019	
Geomorphol	1	1	0.111	0.25	1	0.333	1	0.2	1	4	0.03766	0.082

ogy												
LULC	5	3	0.333	5	4	3	5	1	4	6	0.180155	
TWI	0.333	0.5	0.111	1	0.5	0.333	1	0.25	1	4	0.036144	
NDVI	0.25	0.333	0.111	0.2	0.333	0.143	0.25	0.167	0.25	1	0.016518	

Table 14c AHP scores of factors, weights, and consistency ratio (CR) for Chamoli

Factors	Elevation	Slope	Rainfall	Drainage Density	Soil	Geology	Geomorphology	LULC	TWI	NDVI	Priority (%)	CR
Elevation	1	1	0.111	0.333	5	0.5	1	0.2	3	4	0.058717	
Slope	1	1	0.111	1	1	1	1	0.333	2	3	0.052313	
Rainfall	9	9	1.000	9	9	9	9	3	9	9	0.414712	
Drainage Density	3	1	0.111	1	4	0.5	4	0.2	1	5	0.075874	0.082

Soil	0.2	1	0.111	0.25	1	0.2	1	0.25	2	3	0.034889	
Lithology	2	1	0.111	2	5	1	3	0.333	3	7	0.093019	
Geomorphology	1	1	0.111	0.25	1	0.333	1	0.2	1	4	0.03766	
LULC	5	3	0.333	5	4	3.000	5	1	4	6	0.180155	
TWI	0.333	0.5	0.111	1	0.5	0.333	1	0.25	1	4	0.036144	
NDVI	0.25	0.333	0.111	0.2	0.333	0.143	0.25	0.167	0.25	1	0.016518	

Table 15 Classification of flash flood susceptibility and corresponding area in percentage

Flash flood susceptibility class	Area in %		
	Tehri Garhwal	Rudraprayag	Chamoli
Very low	29.96	23.84	36.95
Low	33.75	22.90	13.18
Moderate	25.98	24.36	30.83
High	8.53	15.41	15.43
Very High	4.77	13.48	3.61

Flash flood susceptibility map of Tehri Garhwal (Figure 22a) indicates that 29.96% and 33.75% of the total district area is classified into very low and low flash flood susceptibility zone while 25.98% of the total area has moderate flash flood susceptibility. 8.53 % and 4.77 % of the total district has high and very high flash flood susceptibility. Flash flood susceptibility map of Rudraprayag (Figure 22b) shows that 23.84% and 22.9% of the district's area fall under very low and low susceptibility to flash flood respectively. 24.36% of the area is classified under moderate flash flood susceptibility, whereas 15.41% and 13.48% of the district's area falls under high and very high flash flood susceptibility. Similarly, flash flood susceptibility map of Chamoli district (Figure 22c) shows that 36.95% and 13.18% of the district's area fall under very low and low susceptibility to flash flood respectively. 30.83% of the area is classified under moderate flash flood susceptibility, whereas 15.43% and 3.61% of the district's area falls under high and very high flash flood susceptibility.

Multi hazard Susceptibility Analysis

To prepare the multi hazard susceptibility hazard map for the study district, the individual hazard susceptibility for all study districts are overlaid using the Weighted Overlay Function tool in ArcGIS 10.7.1. Since the study area is at constant risk to all three hazards, it is assumed that each had the same relative importance and employed equal weights when preparing the integrated multi hazard map (Collins et al. 2009).

The integrated hazard map—prepared by combining the individual landslide, flood, and forest fire hazard maps for Tehri Garhwal, Rudraprayag and Chamoli is presented in Figure 23a-c.

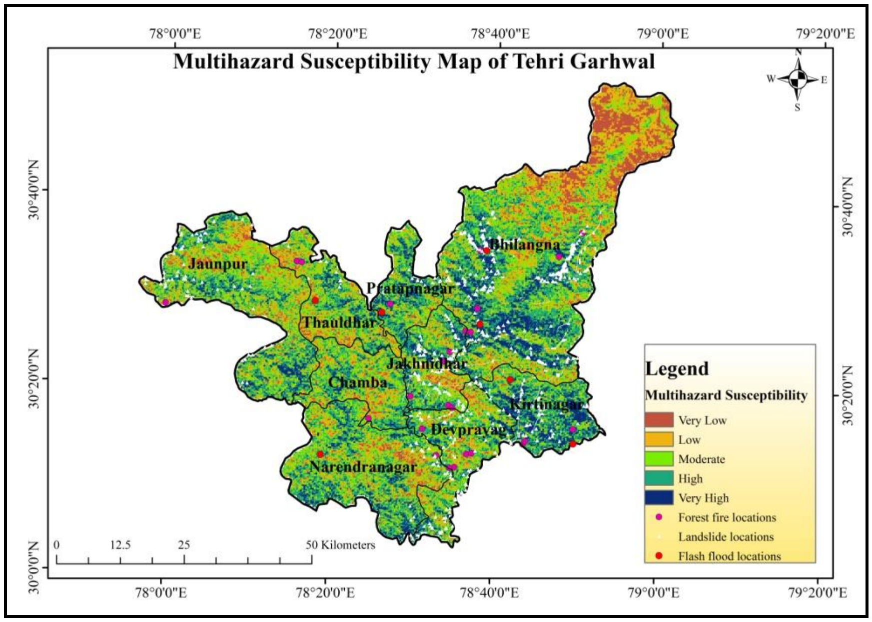


Figure 23a: Multi hazard susceptibility map of Tehri Garhwal

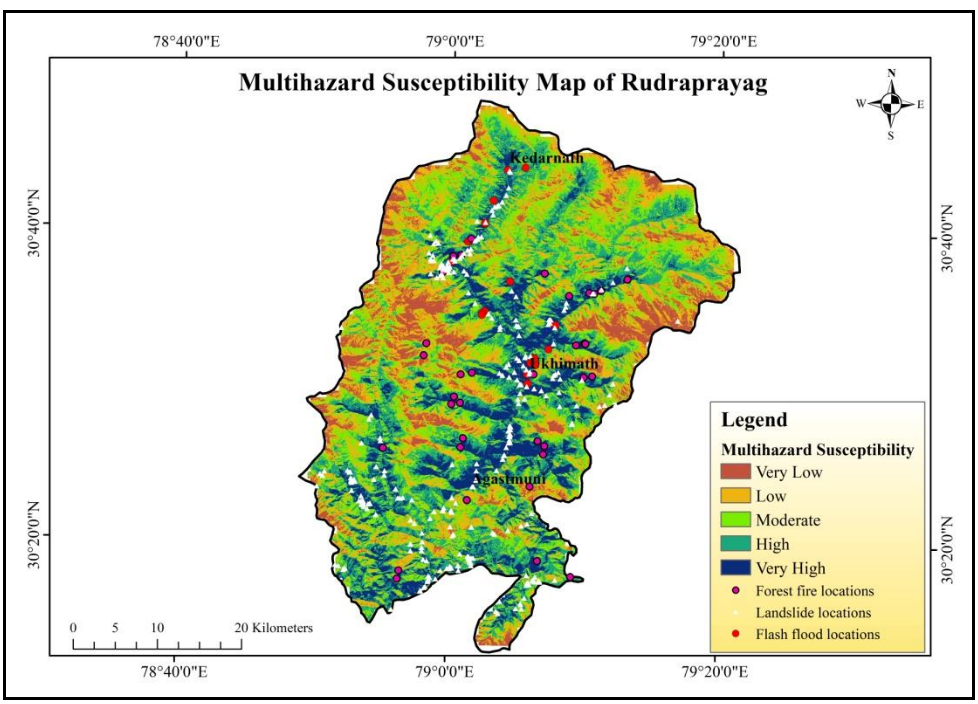


Figure 23b: Multi hazard susceptibility map of Rudraprayag

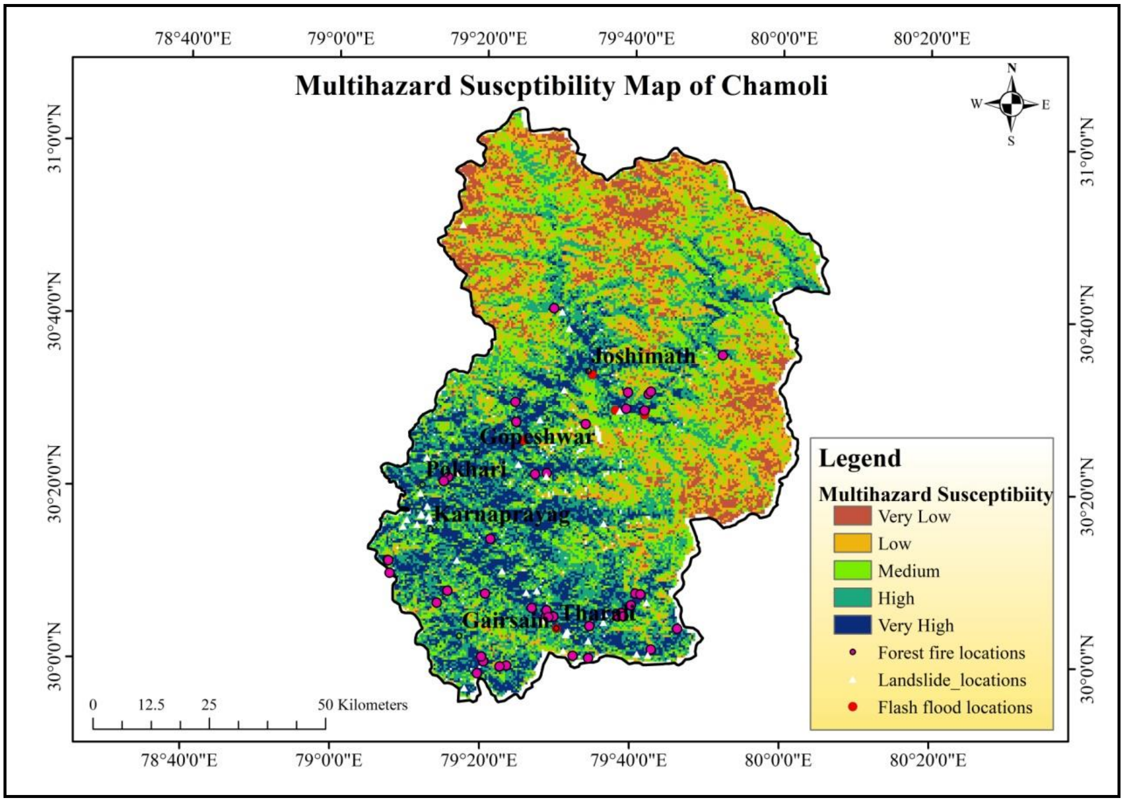


Figure 23c: Multi hazard susceptibility map of Chamoli

Multi hazard susceptibility map of Tehri Garhwal (Figure 23a) shows that Kirtinagar block has high multi hazard susceptibility followed by Bhilangna, Pratapnagar and Jakhnidhar constituting the eastern part of the district. Chamba block is found to have lowest susceptibility to natural hazards. Multi hazard susceptibility map of Tehri Garhwal depicts that the around 40.32% of the total area of the district has high to very high vulnerability to multi hazard, 29.21% of the area has moderate possibility of multi hazards and only 8.81% of the district's area has very low possibility of multi hazards.

Multi hazard susceptibility map of Rudraprayag (Figure 23b) shows that most of the area classified under high to very high multi hazard susceptibility is concentrated near Ukhimath, Kedarnath and Agastmuni region. These regions have repeated history of natural disaster occurance. Multi hazard susceptibility map of Rudraprayag indicates that 11% and 23.39% of the total district area is classified into very low and low flash flood susceptibility zone while 27.31% of the total area has moderate flash flood susceptibility. 24.53 % and 13.76 % of the total district has high and very high multi hazard susceptibility.

Multi hazard susceptibility map of the Chamoli district (Figure 23c) demonstrate that the southern part of the district is more prone to the multi hazard susceptibility compared to the northern part.

Areas near Joshimath, Gopeshwar, Pokhari, Karanprayag, Tharali and Gairsain have high to very high multi hazard susceptibility. Multi hazard susceptibility map of Chamoli district shows that 10.38% and 20.61% of the district's area fall under very low and low susceptibility to multi hazards respectively. 27.17% of the area is classified under moderate multihazard susceptibility, whereas 25.54% and 16.30% of the district's area falls under high and very high multi hazard susceptibility (Table 16). Out of the three studied district Chamoli has the highest multi hazard susceptibility followed by Rudraprayag and Tehri Garhwal

Table 16 Classification of Multi hazard susceptibility and corresponding area in percentage

Multihazard susceptibility class	**Area in percentage**		
	Tehri Garhwal	**Rudraprayag**	**Chamoli**
Very Low	8.81	11	10.38
Low	21.66	23.39	20.61
Moderate	29.21	27.31	27.17
High	27.53	24.53	25.54
Very High	12.79	13.76	16.30

Accuracy assessment: Multi hazard susceptibility maps of Tehri Garhwal, Rudraprayag and Chamoli districts are validated on the basis of hazard density (landslides, forest fire and flashfloods), which is the ratio of the number of hazard in each class to the total number of the hazard points. For allthe three district, the natural hazard density increases as the hazard class increases. This validates the zonation maps since the zones of higher hazard coincide with larger incidences of hazards (Table 17).

Table 17 Hazard density of the hazard class for the multi hazard maps

District	**Multihazard class**	**Number of hazards**	**Hazard density**
Tehri Garhwal	Very Low	11	0.02
	Low	43	0.06
	Medium	149	0.22
	High	231	0.34
	Very High	246	0.36
Rudraprayag	Very Low	6	0.02
	Low	20	0.06
	Medium	52	0.15

	High	110	0.31
	Very High	164	0.47
Chamoli	Very Low	2	0.02
	Low	3	0.04
	Medium	15	0.18
	High	21	0.25
	Very High	44	0.52

Objective2: Quantification of disproportionate opportunities of women in disaster management.

Risk Awareness: An individual's level of threat appraisal according to a gender perspective was investigated in order to assess risk awareness among the people. The results showed that men scored higher (87.7%) than women. This can be explained by one's level of education. That is, women with greater knowledge of natural disaster occurrence (and maps) were found to have a higher level of education. Furthermore, married women and men were found to have more knowledge than single-person families. It appears that single-headed households did not have the same concerns as two-headed households, which could be attributed to carry-over from increased responsibilities in the family context. When people were asked to rate their knowledge of the effects of natural disasters on their health, it seemed that women (79.1%) were more sensitive to these effects than men (76.8%). This might be attributed to a mix of gender effects and women's employment status. Though most women in Uttarakhand work in the agricultural fields but they also are housekeepers and child carers, which makes them more likely to be more sensitive to environmental threats.

Disaster preparedness: Other important objective of this study is to forecast disaster related behaviors based on a future scenario. As per the transtheoretical model of change (FEMA, 2006) the pre-contemplation, contemplation, preparation, and action stages can be used to conceptualize preparedness behavior readiness. In total 500 interviewees responded to the question "what stage of preparedness do you feel in response to the possible natural hazard event"? The highest percentage consisted of those who are not prepared at present but intends to take certain activities (if opportunities provided) in next six months (Contemplation) with a value of 60.3%. Additionally, the males tended to report more active stages of change (preparation, action, maintenance) than the females (Table 19).

Table 19 Preparedness level from gender perspective based on transtheoretical model

Preparedness level	Description	Male	Female
Pre-Contemplation	An individual does not intend to change in near future.	22%	16%
Contemplation	An individual is not prepared presently but intended to undertake certain activities in near future.	62%	53%
Preaparation	An individual has considered changing his/her behavior in the next six month	20%	22%
Action	An individual has changed his/her behavior in the recent past.	5%	6%
Total		100%	100%

When respondents were asked to their level of preparedness at the individual, household, community, and national levels, women expressed lower levels of self-confidence in being prepared for a natural hazard event. The same pattern of results was found for household preparedness highlighting that women were not as confident in household readiness as men. Less preparedness towards natural disaster in women can be attributed to the cultural barriers such as family marginalization, low level of involvement in the communities, and less preferential treatment for women. Apart from that women are more realistic in assessing personal and household preparedness. The lack of preparedness was associated with the lack of capacity and willingness. Men on the other hand are found to be more likely to take preventive measures. Women, on the other hand, stated that they did not have time to deal with these issues. Women's many household, child-rearing, and related responsibilities may lead to a focus that leaves them with less time to consider the additional responsibility of being prepared for a possible natural hazard event.

Preparedness level is found to be related to the education, marital status and income. Educated women were found to be more prepared as compared to uneducated one. In terms of age, younger females and males felt more prepared than adults and elders, perceiving a higher level of preparedness as individuals and households. Married women believe they are better prepared to deal with the negative effects of natural disasters on both levels. Female-headed households perceived themselves to be more vulnerable to natural disasters than their counterparts with both spouses. This could be explained by the fact that households with both spouses are in a better financial and psychological position. As a result, they are in a better mental and emotional state to respond to flood risks than their single counterparts.

People with more possessions and income feel less vulnerable to a negative occurrence and are better able to manage an emergency. A higher level of preparedness was associated with a greater awareness of natural disaster risks. This means that an effective natural disaster preparedness and mitigation campaign could result in effective individual and household preparedness and mitigation measures.

Information and education: When people were asked to state the source from which they received information on natural disasters, a gender-based relationship emerged Women stated to be informed by technological sources (television, press, and the Internet) and family; while their male counterparts, reported to rely more on neighbors, friends, and the place of work for their information. This might be explained by the fact that women are typically confined in the house, for their work and child rearing, making them isolated from various sources of communication, except other family members.

Objective 3: To identify the multi-hazard induced vulnerabilities by the local communities with special reference to women in the area.

Outcomes of focused group discussions:

Participants reported significant concerns about natural disasters in the study area especially, cloudbursts, thunderstorm, landslides are often cited as examples of natural disasters in their communities.

- Seventy-five percent of the participants cited loss of life, property, jobs, and difficulty with family reunification as the consequences of a disaster. However, disruption of essential services is rarely mentioned (25%). Most of the males work in hotels (58%), local shops (23%) whereas majority of the females work in agricultural fields nearby their house (68%). Therefore, Females are the first one to experience the consequences of natural disasters.
- Almost 80% participants expressed lack of knowledge about disaster management plan and institutional framework. Therefore, they are unaware of the process of claim for loss during natural disasters. Participants are interested in participating in awareness program or training related to disaster managements.
- Village heads are females but they are unaware of the government schemes running in their area.
- 90% participants cited considerable loss of agricultural fields over the time and face lots of challenges in growing crops due to destruction of crops by monkeys and wild pigs in the area.

Majority of the respondents 53% (agreed and emphasized that education among the women would certainly contribute to minimize the out-migration to plains. They highlighted that poverty, poor health, and education are inter-linked and also put unwanted pressure on natural resources. Low levels of literacy and entrepreneurial skills among women not only creates adverse impact on environment and but also intensifies the struggle for livelihood. The respondents opined that their focus and energy need to be channelized by providing skill/training in agriculture, organic farming and other income generating activities focused on the locally available bio-resources. If women are educated their level of understanding increases and the grasp on things allows them to take benefit of such awareness and capacity building programs in a much more fruitful manner. On the other hands, above 47% respondents expressed that improving education and developing skills of women of the affected areas is not the only solution to control out-migration. They opined though education brings a change in mindset and behavior but due to limited employment opportunities and lack of quality schools, education has failed in controlling the tide of migration. They also shared that in the aftermath of the disaster now the families are migrating out due to the safety issue, education of children and earning livelihood. According to them, the more educated the family is, the more is the rate of migration. To check the rate of migration they emphasized the need to develop good quality educational institutions, medical and other facilities necessary for leading a fulfilling human life in the region.

Based on the questionnaire survey FDGs and subsequent findings following factors were identified which defines the women's vulnerability in natural disasters:

Socio-cultural

Socio-economic

Individual characteristics

Legal/Institutional

Socio-cultural: Socio-cultural factors such as Patriarchal culture, religious belief, household work load, household size could be considered important indicators for women's vulnerabilities.

Socio-economic: Household income is identified as the determinant factor of socio-economic condition. It generally leads to lower level of engagement of women in decision making at house hold level.

Individual characteristics: Characteristics of an individual such as their education level and self-interest are identified as important factors governing low level engagement of women in decision making limiting their role in disaster management.

Legal/ Institutional: Based on the literature survey and interaction with focused group in the study area, political environment, policies and legislations and organizational cultures are recognized as the important indicators to know the roles and opportunities of women in disaster management.

Key Results

- The Resultant Landslide susceptibility map (LSM) of Tehri Garhwal classified the district into five classes ranging from very low to very high susceptibility. About 34.1% area falls in moderate landslide susceptibility class while 28.4% of the total district has high and very high landslide susceptibility. Areas having high to very high susceptibility includes Bhilangana, Pratapnagar, Jakhnidhar and Kirtinagar blocks. The susceptibility map is validated using area under the ROC which shows 51% success rate and 56% prediction rate.
- LSM of Rudraprayag indicates that 10.04% and 23.56% of the total district area is classified into very low and low landslide susceptibility, whereas 24.68% of the district's area is grouped under moderate class. Around 41.42% of the total area of Rudraprayag has high to very high landslide susceptibility. Areas near Ukhimath, Kedarnath and Agastmuni are found to have very high landslide susceptibility.
- LSM of Chamoli showed that around 45% of the total area has high to very high landslide susceptibility. Areas near Joshimath, Gopeshwar, Pokhari and Karanprayag are found to be susceptible for landslide hazard.
- Forest fire susceptibility map of Tehri Garhwal showed that 31.47 % and 17.05 % of the total district has high and very high forest fire susceptibility. Bhilangna, Jaunpur and Kirtinagar, Chamba and Jakhnidhar blocks are found to be more susceptible to forest fire, which is confirmed by the field visits and secondary sources.
- Forest fire susceptibility map of Rudraprayag indicates that 23.50% and 11.49% of the district's area falls under high and very high forest fire susceptibility. The potential areas for forest fires are concentrated mostly in the Rudraprayag block of the district. In addition, very high fire susceptibility areas are found mostly in the areas having high land surface temperature in the southern area of the study area
- 25.49% and 15.78% area of the Chamoli district falls under high and very high forest fire susceptibility. The potential areas for forest fires are concentrated mostly in the Tharali, Gairsain, Karanprayag and Pokhari blocks of the district.
- Out of the total area of Tehri Garhwal, 8.53 % and 4.77 % has high and very high flash flood susceptibility respectively, 15.41% and 13.48% of the Rudraprayag's area falls under high and very high flash flood susceptibility whereas 15.43% and 3.61% of the Chamoli's total area falls under high and very high flash flood susceptibility.
- Kirtinagar block of Tehri Garhwal has highest multi hazard susceptibility followed by Bhilangna, Pratapnagar and Jakhnidhar constituting the eastern part of the district. Chamba block is found to have lowest susceptibility to natural hazards.

- In Rudraprayag district, the area having high to very high multi hazard susceptibility is concentrated near Ukhimath, Kedarnath and Agastmuni region. These regions have repeated history of natural disaster occurrence.
- Southern part of the Chamoli district is more prone to the multi hazard susceptibility compared to the northern part. Areas near Joshimath, Gopeshwar, Pokhari, Karanprayag, Tharali and Gairsain have high to very high multi hazard susceptibility.
- Out of the three studied districts, Chamoli has the highest multi hazard susceptibility followed by Rudraprayag and Tehri Garhwal.
- Household survey revealed that the men have higher risk awareness as compared to women in the study area. This can be linked to the level of education as women with higher education have more awareness towards natural hazard related risk as compared to the women who have low level of education.
- Women (79.1%) were found to be more sensitive towards the effects of natural hazards on the health than men (76.8%). Most women in the study area work in the agricultural fields but they also are housekeepers and child carers, which makes them more likely to be more sensitive to environmental threats.
- Women are found to have lower levels of self-confidence in being prepared for a natural hazard event. The same pattern of results was found for household preparedness highlighting that women were not as confident in household readiness as men. Less preparedness towards natural disaster in women can be attributed to the cultural barriers such as family marginalization, low level of involvement in the communities, and less preferential treatment for women.
- Almost 80% participants expressed lack of knowledge about disaster management plan and institutional framework. Therefore, they are unaware of the process of claim for loss during natural disasters. Participants are interested in participating in awareness program or training related to disaster managements.
- 90% participants cited considerable loss of agricultural fields over the time and face lots of challenges in growing crops due to destruction of crops by monkeys and wild pigs in the area.
- Majority of the respondents 53% (agreed and emphasized that education among the women would certainly contribute to minimize the out-migration to plain, on the other hands, above 47% respondents expressed that improving education and developing skills of women of the affected areas is not the only solution to control out-migration. To check the rate of migration they emphasized the need to develop good quality educational institutions, medical and other facilities necessary for leading a fulfilling human life in the region.

- Based on the questionnaire survey FDGs and subsequent findings following factors were identified which defines the women's vulnerability in natural disasters:

  - Socio-cultural
  - Socio-economic
  - Individual characteristics
  - Legal/Institutional

3.3 Conclusion of the study undertaken

- This study offers a composite susceptibility assessment model for the study districts of Uttarakhand based on geospatial data and techniques in combination with social data. This was accomplished by assessing and combining risk from three natural hazards (landslides, floods, and forest fires) and subsequently developing a multi-hazard risk model that collectively considers the three types of hazards.
- The study is primarily based on publicly available remote sensing imagery and socioeconomic data collected through fieldwork and from key informants in the communities.
- Landslide inventory map can be helpful in clear demarcation of relatively safe and unsafe zones. It is highly recommended that any constructional activities in the close proximity of landslides should necessarily be backed by appropriate geological-geotechnical assessments.
- Individual hazard zonation maps (landslides, forest fires, flash floods) and multi hazard susceptibility maps of the districts under study helped identifying the areas having high to very high susceptibility to one or more than one natural hazard. In Tehri Garhwal, Kirtinagar, Jakhnidhar, Bhilangana and Pratapnagar block are found to have high to very high multi-hazard susceptibility. Areas near Ukhimath, Agastmuni, Kedarnath in the Rudraprayag district has very high multi hazard susceptibility. Similarly, In Chamoli district, Joshimath, Karanprayag, Gopeshwar, Pokhari and Gairsain is having high to very high multi-hazard susceptibility.
- The susceptibility map of the investigated districts provides sufficient information about present and future natural hazards for public, engineers, and planners to mitigate construction issues caused by natural hazard. Remedial measures can be applied for high/very high zones by engineering techniques using these susceptibility maps.
- House hold survey was performed in the areas that have multi-hazard susceptibility to identify the social vulnerability in the form of gender based parity.
- In present study gender differences were found in study area regarding a range of natural hazard preparedness indicators. Although there were some variables that indicated slight differences, larger magnitude and significant differences appeared to revolve around men's perceptions of

being more prepared and being more active or willing to be involved in or led by community-level activities.

- Women generally reported being less confident, but perhaps had more realistic views about being prepared while also reporting more household- and family-level cares, concerns, and preparedness behaviors. Such a pattern may be underpinned, at least to some extent, by gender-specific roles linked to the household and to community access, leading to a state of affairs that lead to less ability to connect with active social networks within the community, coupled with being less informed and able to be involved in larger decision-making processes.
- Socio-cultural, socio-economic, individual characteristics and legal/institutional factors are found to be the important factors in defining the vulnerabilities of women in disaster management.
- This study can be replicated in other data scarce regions that are at risk to multiple hazards. Additionally, results from this approach can assist decision makers to better understand comprehensive risk and, consequently, to design more effective and spatially targeted policies to increase capacity and resilience.
- The results of this study can serve as the basis for targeting prioritization efforts, emergency response measures, channelizing funds, and raising environmental concern and policy interventions at district level for mitigating disaster vulnerability in the country.

OVERALL ACHIEVEMENTS

4.1 Achievements on Objectives

To identify the susceptibility of multi-hazards in the study area and demarcation of zones which are at high/ very high risks.

- The individual hazard susceptibility maps of the study area provide essential information on the areas having high and very high risk of natural hazards. Further the integrated map (multi hazard susceptibility map) provides information on the areas susceptible to one or more than one natural hazard. Thematic layers prepared to analyze the individual hazards, provides spatial information on various parameters such as rainfall, slope, aspect, geology, geomorphology, soil, elevation, LULC, drainage density, land surface temperature, NDVI TWI etc. for the studied districts.
- The geospatial technologies along with multi decision criteria analysis (AHP) are used to generate the landslide, forest fire, flash flood and multi-hazard maps for the study areas.
- The multi hazard susceptibility maps classified the studied districts into five classes such as very low, low, moderate, high and very high susceptibility. Out of the three studied districts,

Chamoli is found to have highest multi hazard susceptibility followed by Rudraprayag and Tehri Garhwal.

Quantification of disproportionate opportunities of the women in disaster management.

To identify the multi-hazard induced vulnerabilities by the local communities with special reference to women in the area.

- The disproportionate opportunities of the women in disaster management are studied through household survey on factors such as risk awareness, disaster preparedness and information & education. Women are found to have lower level of risk awareness as compared to men, however the sensitivity towards the health issues is found to be more in women.

- The research also shows how living conditions, demographic and economic attributes, behaviors and beliefs reflect gender power relations in the context of disaster management. Once the factors contributing to the women vulnerability are recognized, disasters and disaster preparedness can also be seen as opportunities to facilitate or provide openings for the empowerment of traditionally marginalized groups such as women.
- Assessing gender discrepancies can help policy makers recognize local capacities and provide prospects for the less powerful to make disaster preparedness and relief more effective. The failure in understanding local relationships and social networks may disadvantage communities including women, men and their families and networks who face these events.

- Based on current findings coupled with other research on different gender profiles, both women and men should be seen as valuable resources that might combine complementary strengths to maximize preparedness, response, and recovery. That is, promoting more gender-related dialogue that aims to leverage the respective strengths of women and men and requires women to be increasingly empowered to take leading roles in building disaster resilience.

- Men appeared to be more confident in managing an emergency situation, including the perception that they were better prepared to take action, including physical preparedness and response. Additionally, women had fewer opportunities to maintain a high level of social networking in the community, which may lead to them being less informed.

4.2 Establishing New Database/Appending new data over the Baseline Data

- Landslide susceptibility maps of the study districts through AHP using various causative factors such as rainfall, slope, aspect, NDVI, TWI, geology, soil, road proximity and drainage density.
- Forest fire susceptibility maps of the study districts through AHP using slope, aspect, drainage density, elevation, LULC, NDVI, LST, rainfall, road and settlements as causative factors.
- Flash flood susceptibility maps of the study districts through AHP analysis using elevation, slope, rainfall, drainage density, soil, geology, geomorphology, LULC, TWI and NDVI.
- Integrated maps depicting multi-hazard susceptibility of the study district has been prepared.

Addressing cross cutting issues: One of the main cross cutting issues of women equity is addressed by this study. In this study an attempt has been made to measure the difference in gender vulnerabilities to understand who will be at higher risk during and after disaster. The study will facilitate identification of causative factors for vulnerabilities so that the contingency plan and disaster management plan could be reframed in order to achieve gender equity.

(a) Low levels of literacy and entrepreneurial skills among women

(b) Cultural, socio economic, barriers making women more vulnerable to natural disasters

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Photographs taken during Focussed group discussions, household survey and key informants interviews

Photographs taken duing field survey

(a) Jhaki Dagar 1 landslide

Coordinates:

30º18’02.55”N

078º43’03.85”E

Elevation: 1124m

(b) Jhaki dagar 2 landslide

Coordinates:

30º20’45.58”N

078º41’49.45”E

Elevation: 1279m

(c) Belta 1 landslide

Coordinates:

30º20’45.40”N

078º41’49.36”E

(d) Belta 2 landslide

Coordinates:

30º20’35.69”N

078º41’58.99”E

Elevation: 1217m

Elevation: 1172m

(e) Belta 4 landslide

(f) Dhaulangi landslide

Coordinates:
30º19'07.04"N
078º43'20.54"E
Elevation: 1174m

Coordinates:
30º19'38.96"N
078º39'10.41"E
Elevation: 1053m

(a) Hadi Sera landslide

(b) Berani Chhoti landslide

Coordinates:
30o14'32.86"N
078o21'30.27"E
Elevation: 1092m

Coordinates:
30o14'12.09"N
078o21'21.33"E
Elevation: 1139m

(c) Fakot 1 landslide

Coordinates:
30o13’46.40”N
078o21’07.78”E
Elevation: 1191m

(d) Fakot 2 landslide

Coordinates:
30o13’43.99”N
078o20’57.58”E
Elevation: 1199m

(e)Fakot 3 landslide

Coordinates:
30o13’37.95”N
078o21’18.66”E
Elevation: 1281m

(f) Agar landslide

Coordinates:
30o13’22.09”N
078o19’52.68”E
Elevation: 1352m

(g) Agrakhal landslide

Coordinates:

30o12’49.74’’N

078o19’40.90’’E

Elevation: 1434m

(h) Semali Katal landslide

Coordinates:

30o12’14.61’’N

078o19’32.47’’E

Elevation: 1421m

(i) Pildi landslide

Coordinates:

30^{o}08’15.60”N

078^{o}17’16.07”E

Elevation: 913m

COMPREHENSIVE REPORT BY HJRF

Executive Summary

Watershed is a spatial unit that includes diverse natural resources (soil, water, trees, biodiversity and others) that are unevenly distributed within a given geographical area. A watershed is also a hydrological response unit, a biophysical unit, and a holistic ecosystem. Besides, being a useful unit for physical analysis, it can also be a suitable socioeconomic-political unit for management, planning and implementation (Wang et al. 2016). People and livestock are an integral part of watershed and their activities affect the productive status of watersheds and vice versa. Watershed also plays a crucial role in determining food, social, and economical security and provides life support services to rural people (Wani et al. 2008). Watershed management integrates decision-making processes to help assess the nature and status of the watershed, identify the watershed issues, define and re-evaluate short- and long-term objectives, actions and goals, assess benefits and costs and implement and evaluate actions (Mwanga, 2007). In present times, sustainable watershed management has become a common process, and sustainability guidelines on watershed management are available for both developed and developing countries to generate better, more locally specific, watershed management strategies.

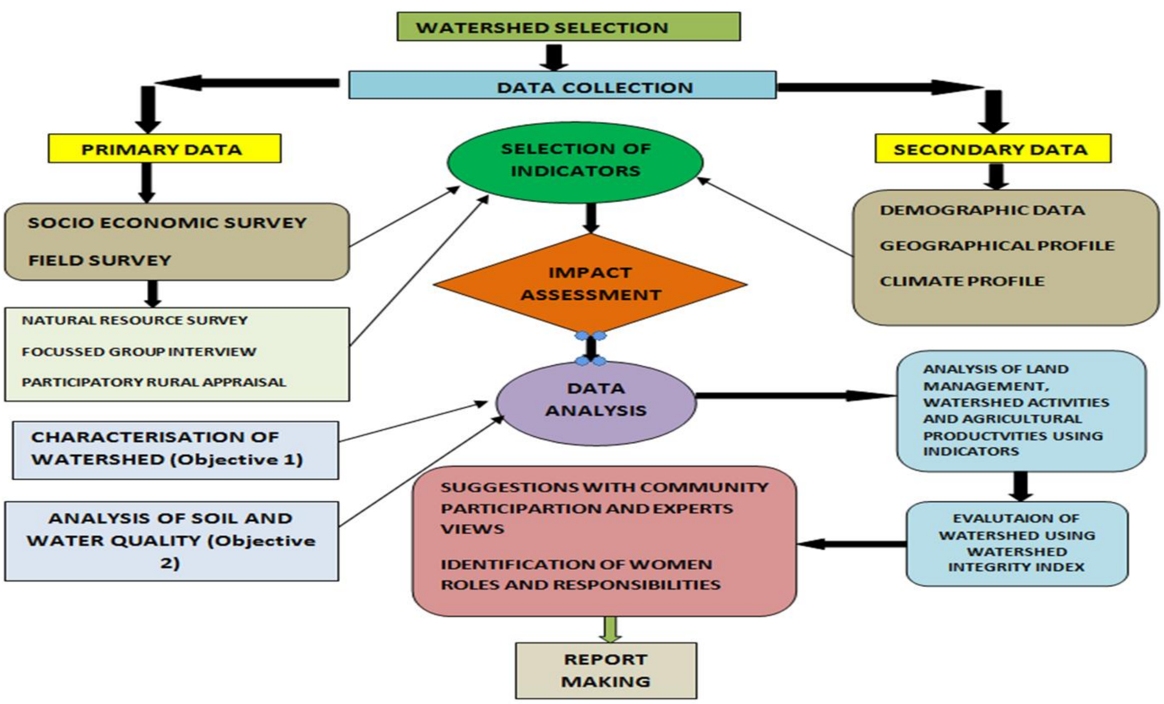
The watershed development programme in India has faced many challenges. It founds its association with serious problems of management that prevent the optimum use of its resources.

The natural resources, economic activities, the availability of the food, health and quality of life all are severally impacted by the climate change. The rural people of the Indian Himalayan region mainly depend on the natural resources their livelihood are greatly threatened by frequent climate change events. The rural livelihoods are likely to bear an uneven burden of the various effects of the climate change. Livelihoods are important for social and economic balances, but frequent climate changes force them to make unfavorable decisions (Podder and Samanta, 2019). In rural Himalayas, women are indeed the managers of natural resources. Participation of women is of paramount importance for the effective managers of community natural resources, and has learned to protect these resources in order to preserve them for future generations (managers of sustainability) (Tiwari & Joshi, 2016). Rural women actively participate in different activities i.e. soil-water conservation, crop production practices, practices for fodder, fuel and vegetable production and other practices like poultry, goat rearing, small scale industry etc. But women’s contribution in sustainable agriculture system and watershed practices has been largely ignored. The impact of watershed development efforts on women is a key issue. Women are more reliant not only on common property forest resources for survival and income, but also they are more often responsible for fuelwood, fodder and water collection (Singh, 2015). Degradation of watersheds negatively affects the health, income, and work burden of women and girls. The use of a

gender-sensitive approach to watershed management remains paramount ensuring that women's and men's unique needs, priorities, and knowledge are incorporated into management plans and policies. It may be noted that the income-generating activities are often non-land based; this may further marginalize the landless and women from attaining equitable access/control over productive resources. The watershed development program in India has faced many challenges. In reality the watershed program continues to be primarily land based and landowner focused and therefore 'male-focused', given the control of land ownership in India and does not take adequate account of the role women play in the rural economy (Jodha, 2002).

In this background the present study aimed at characterizing the watershed on the basis of the available natural resources of Takoli Gad watershed, Tehri Garhwal. Further, the individual maps are used to generated to identify the resource potential zone of the watershed. Analysis of various water and soil parameters explains the impact of anthropogenic activities on the watershed. Household surveys, focused group discussions and key informant's interviews are conducted in the regions to find out the indicators to develop the watershed integrity index of the Takoli gad watershed and to identify the various activities that women contribute in managing the natural resources sustainably.

The methodology followed during the present study is described in the flow chart:



Outcomes: The broad outcomes of the Project have been enlisted as per the objectives:

	Objectives	Outcomes
1.	Characterization the watershed on the basis of available resources	• Delineation of the Takoli Gad watershed • Morphometric analysis of the watershed i.e. linear aspect, areal aspect and relief aspect • Preparation of the various thematic maps that are factors identified for the estimation of the natural resources potential zones such as elevation, slope, rainfall, LULC, Geology, drainage density, and soil types in the watershed. • Identified resource potential zones that are classified into 5 classes i.e. excellent, moderate, good, poor and very poor zones.
2.	Assessment of physiochemical parameters of soil and water in the watershed.	• Various water physicochemical parameters were analysed for monsoon and post monsoon season i.e. pH, electrical conductivity, TDS, total hardness, calcium, magnesium, chloride, alkalinity, sodium, potassium. The outcomes were validated by comparing with WHO (2011) and BIS (2012) criteria for drinking water quality. As per the BIS and WHO standard value of drinking water, spring water samples are in the acceptable cap. • Water quality index (WQI) is calculated for the three different sampling season for pre monsoon, monsoon and post monsoon. • Various physicochemical parameters of soil were analysed for monsoon and post monsoon season i.e. pH, electrical conductivity, bulk density, soil moisture, soil organic carbon, total nitrogen, available phosphorous, available potassium, available sulphur and micronutrients (Copper, Manganese, iron and zinc) for different

		land use pattern i.e. forest land, agriculture land, settlement land and waste land. The values are validated by comparing soil health card, ICAR in which results varies by depth.
3.	Watershed integrity index of the studied area.	• "Watershed Integrity Index of the Takoli Gad watershed" will be the part of the PhD thesis. This objective will be compiled in the PhD thesis work.
4.	Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability.	• Identified the role of the women in watershed management. • Created awareness among local communities towards watershed management. • Identified the differential aspects that are limiting the roles of women in the study area.

1 INTRODUCTION

1.1 Background of the project

The available natural resources are essential for the sustainable life which are becoming limited due to various factors like growing population, deforestation owing to growth of agricultural activities, small land holdings, lack of irrigation facilities, and urbanization which reduces the infiltration rates, and heavy soil erosion, landslides, declining soil fertility and frequent crop failures, resulting in scarcity of food, fodder and fuel, changes in land use land use cover. Hence, proper management and conservation of natural resources is critical (Panhalkar et al. 2012; Malik and Bhat, 2014; Kushwaha and Bhardwaj, 2017). Watershed development has been conceived basically as a strategy for protecting the livelihoods of the people inhabiting the fragile ecosystems experiencing soil and moisture stress. The aim has been to ensure the availability of drinking water, fuel wood and fodder and raise income and employment for farmers and landless laborers through improvement in agricultural production and productivity (Rao, 2000).

In rural Himalayas it is common that women are indeed the managers of natural resources. These resources comprise land, water, forests and flora and fauna. Most rural women are comparatively poor and uneducated. Such women are brilliant upholders of indigenous natural resources awareness. The role of woman is crucial, as they are in direct contact with these natural resources and use them to feed their families (Anantha et al., 2009; Shah et al., 2013). More focus, however, is required on people's participation, empowerment of community, gender neutrality, equity, transparency and management of common property resources. Participation of women is of paramount importance for the effective managers of community natural resources, and has learned to protect these resources in order to preserve them for future generations (managers of sustainability) (Tiwari & Joshi, 2016).

The Self-Help Groups (SHGs) in micro watersheds have received much attention from the policy makers. The SHGs are formed mostly for Women-oriented activities. Women are responsible for over half the food production in developing countries. The major component of women's labour in crop production is utilized in transplanting, weeding and harvesting activities. These activities are arduous, time-specific and critical operations, and determine the productivity of crops. Rural women actively participate in different activities i.e. soil-water conservation, crop production practices, practices for fodder, fuel and vegetable production and other practices like poultry, goat rearing, small scale industry etc. But women's contribution in sustainable agriculture system and watershed practices has been largely ignored. The impact of watershed development efforts on women is a key issue. The success of women's involvement has varied for many reasons, including inadequate project design, cultural and social constraints, as well as policy and legal constraints. In most developing countries, women are responsible for household water collection as well as water use and management, including hygiene within the household and community (Upadhyay et al., 2005). Men are perceived to be responsible for production and management of farms or small businesses, even though women are very much involved in these enterprises. Despite women's significant role in water use and household management, women's needs and uses of water are often not represented in water resource management policies or projects (Padmaja et al., 2020). Women possess incomparable knowledge of local ecological and water conditions due to their gendered roles and responsibilities, and this knowledge would benefit local, national, and international negotiations and decision making processes in terms of social justice and resource use efficiency. IWM in India was basically adopted to check land degradation and increase the agricultural productivity. So, the very notion of involving women was never thought off as agricultural pursuits are largely done by men in the country (Singh, 2015). This was a mistake as the hilly tracts of the country have always seen women at the helm of the agricultural pursuits. If the way the watershed programme that is currently viewed could be changed and looked into as 'rural livelihoods' rather than as a land development programmes, women and the poorer marginal farming households will benefit, given their dependence on many non-land based activities. Finally, there is a need to ensure that women do not become overwhelmed by the schemes and programmes focused on them. They need to be able to make informed choices about where to invest their time. Women's participation in IWM remains an important component of people's participation. Because women (young and old) are more reliant not only on common property forest resources for survival and income, but also they are more often responsible for fuelwood, fodder and water collection (Singh, 2015). Degradation of watersheds negatively affects the health, income, and work burden of women and girls. The use of a gender-sensitive approach to watershed management remains paramount ensuring that women's and men's unique needs, priorities, and knowledge are incorporated into management plans and policies

Healthy watersheds play a key role in providing habitat for wildlife, clean water for healthy aquatic ecosystems, and safe drinking water, adapting to climate and land use changes. The watershed morphometric study provides an accurate quantitative description of the drainage system, which is an important aspect in its characterization (Chauhan et al. 2016). The results derived from watershed morphometric analysis could be used as a critical tool in water resource management, conservation of soil erosion, landslide susceptibility mapping, evaluation of groundwater potential, and prioritization of watersheds (Sreedevi et al. 2009; Sujatha et al. 2014; Singh et al. 2021). Thus, watershed health assessment and sub-watershed prioritization will help implement proper watershed management and adopt and allocate natural resources.

Remote sensing (RS) and geographical information system (GIS) is a unique and powerful tool for procuring spatiotemporal data over a large area in a short duration of time (Allafta et al., 2020). The application of geoinformatics in natural resource management has been recognized as a crucial management and decision making tool that assures best possible use of the resources and facilitates in prudent resource and management approach (Narmada et al., 2015). Many researchers have discovered that AHP technique is an effective tool that can be used in a variety of fields such as natural resource management, regional planning, and environmental impact assessment (Ifediegwu, 2022). The geospatial technique for mapping the physiochemical parameters of ground water are widely used by researchers (Kumar and Sangeeta, 2020). Several attempts have been made to assess watershed health, based on just one factor such as climate, soil erosion, morphometric parameters, water quantity and quality, soil quality or a socioeconomic index. Many researchers have assessed watershed health through different approaches. The goal of this study is to investigate the watershed integrity index using an integrated comprehensive approach. This integrated methodology can be utilized for adopting watershed protection and restoration measures. The developed index will help in the formulation of watershed development plan for the conservation and management of watershed resources sustainably.

1.2 Overview of the Major Issues to be addressed

The watershed management has encountered many threats. Due to lack of baseline data for monitoring and comparison of the current conditions of the watershed leads to natural resource exploitation and ineffective management which lead to the depletion of resources in both quantity and quality. Major problems are adequate shortage of water for general and drinking purposes, equitable benefit sharing of watershed management within the watershed. Usually, land degradation of rain fed area due to soil erosion, common lands do not get treated adequately causes overgrazing and deforestation problems. Major problems exist because of inaccurate perception of the interaction between biophysical and socio-economic processes in watershed management. Conflicts among various government ministries such as those related to agriculture (with emphasis on food production), rural development (with emphasis on employment generation and poverty alleviation), and forest and environment (with emphasis on biodiversity and wildlife), as well as conflict between government bureaucracy and elected representatives to control funds which is the biggest problem in watershed management programmes. Watershed management can be defined as ‘‘the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed function that affect the plant, animal, and human communities within a watershed boundary’’ (Chaves and Alipaz, 2007). Since a large proportion of the investment in watershed projects is allocated to land-based activities, and that access to augmented water for irrigation is also linked to ownership of land, the project benefits are generally tilted in favor of the landed and the men who own the land. Gender issues have been a part of watershed management projects. Development of common property resources (land, water, forest) and formation of self-help-groups (SHGs) for promoting income-generating activities thus, become the main thrust of watershed projects for addressing the issues of landless and women. It may be noted that the income-generating activities are often non-land based; this may further marginalize the landless and women from attaining equitable access/control over productive resources. The watershed development program in India has faced many challenges. In reality the watershed program continues to be primarily land based and landowner focused and therefore ‘male-focused’, given the control of land ownership in India and does not take adequate account of the role women play in the rural economy (Jodha, 2002). It founds its association with serious problems of management that prevent the optimum use of its resources. Till date only qualitative study has been carried out on watershed integrity indices. Therefore, carrying out study in order to understand the watershed integrity index is crucial. So there is a need to identify some useful and practicable indicators to reasonably monitor and assess the impacts of watershed interventions on biophysical, socio-economic and sustainability attributes. Research needs to be presented in a way so that policy makers and managers can integrate knowledge into practical applications.

1.3 Project objectives and Target Deliverables (as per the NMHS sanction order)

Position	Study Area	Proposed Objectives	Deliverables
HJRF01	Uttarakhand	• Characterization the watershed on the basis of available resources • Assessment of physiochemical parameters of soil and water in the watershed. • Watershed integrity index of the studied area. • Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability.	• The basic resources estimation of the study area will provide the base line data about the past and present scenario of the watershed. • Analysis of various water and soil parameters would predict the impact of anthropogenic activities on the watershed. • Survey and PRA activities would result in the understanding of the gap areas and implementation of strong policies and governance. • This would result in the preparation of a more comprehensive plan or development of a new index that are vital for managing and conserving the watershed sustainability. • It would promote financial and food security and improve health and living conditions. • It would upgrade the women's input into decision making processes in families, institutions and village life. • Outcome of the research work will be the part of PhD thesis.

METHODOLOGIES, STRATEGY AND APPROACH

2.1 Methodologies used for the study

(i) Study area

In view of achieving the objectives of the project, Takoli Gad watershed was taken for the study. Takoli Gad watershed is located in Tehri Garhwal district of Uttarakhand and covers an area of 133 km^2 and is bounded between 30^{0}14’ N to 30^{0}23’ N latitudes to 78^{0}37’E to 78^{0}46’ E longitudes. The area falls within inner lesser Garhwal Himalaya and is characterized by gentle and mature topography. Drainage is mainly controlled by major perennial river Alaknanda and its tributaries. The most common drainage pattern in the area is sub dendritic to sub trellis. Agriculture is the most common occupation of the villagers in the study area. Rice, wheat, barley, jhangora and maize are the principal crops. Location map of the study area is shown in Fig.1.

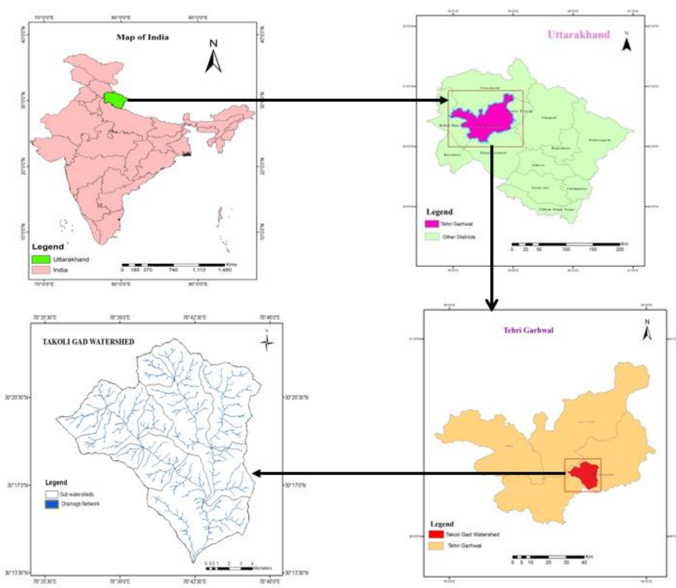


Fig.1 The location map of the study area

(ii) Reconnaissance survey: Primarily, reconnaissance survey was conducted to assess the status of the Takoli Gad watershed in terms of physical, biological, economic and social factor.

(iii) Review of literature: A literature survey was conducted in order to collect the existing information on sustainable watershed management involving local communities. This section was an important part of the study. Information from published journals, books, reports as well as past and present records from government was collected.

For each objective, a number of activities were planned using standard methodologies.

Objective 1: Characterization the watershed on the basis of available resources

Morphometric Characterization: Geo-referenced with precisely orthorectified Global Digital Elevation Model of ASTER 30 m resolution have been used for the present study. The data has been downloaded from the United State Geological Survey (USGS) website. The study area falls under UTM zone of 43N. SOI topographic sheets have been used for extraction of drainage network and delineation of the Takoli Gad watershed. The DEM and slope map have been prepared for the analysis of linear, areal and relief aspects of drainage basin. Basic morphometric features such as area, perimeter, basin length, stream length, and stream numbers have been obtained for all micro-watersheds. The stream order was assigned to each stream using Strahler (1964) stream order technique in GIS. The geo-morphometric study, which is widely used approach for watershed characterization is described as the quantification of drainage basin. The morphometric parameters for all micro-watersheds were estimated using the formula proposed by Horton (1945), Strahler (1964), Schumn (1956), and Miller (1953).

The survey of India (SOI) topographic maps of 1:50,000 scale (53J/11, 53J/12 and 53J/15), land use land cover map is prepared using Indian Remote Sensing Satellite (IRS) LISS IV data of February, 2020, geology map from Geological Survey of India (Geological Survey of India, Kolkata), and soil map is produced by NRSA-IIRS, DoS, Government of India have been geometrically rectified and georeferenced as per the world's space coordinate system using image processing and GIS software (Erdas Imagine and Arc GIS). These geo-rectified maps have been digitized in the GIS environment to produce thematic layer i.e. soil, geology-lithology, drainage network, and land use land cover.

Multi-criteria decision analysis: Multi-criteria decision analysis via analytical hierarchy process is the most popular and well known GIS based approach used for land and water management (Saaty, 1990; Arulbalaji et al., 2019; Abijith et al., 2020; Rajesh et al., 2021, Abrar et al., 2021, Doke et al., 2021). AHP helps in integrating all thematic layers. The weights of the determinant thematic maps were calculated using AHP. The land and water conditioning factors were weighted using a heuristic approach and survey of literature by numerous researchers. The weightages in the present study were assigned after a review of previous studies and field experience. Saaty's scale was used to assign weight to the selected thematic maps. Weights are assigned to the thematic layers based on their significance. Weighted Sum Overlay (WOA) tool was applied to overlay the thematic maps in the Arc GIS

8.2. Using the several researchers approach, a pairwise comparison matrix is generated using Saaty's one to nine scale to specify the priority and rank of the thematic layers. The AHP method was used to calculate the normalized weights of the individual themes. The consistency Index (CI) is calculated from the equation (1) and (2)

Where n is the number of conditioning factors, and λ_{max} is the principle eigenvalue of the matrix. RI value is taken from the (Saaty, 1990) scientific report, and is dependent on the number of components. The weights obtain using the matrix is effective only when CR value is 0.10 or less is considered acceptable to continue the analysis.

$$CR = \frac{CI}{RI} \qquad (1)$$

CI is consistency index, CR is consistency ratio, and RI is the random index

$$CI = \frac{\Lambda max - n}{n - 1} \qquad (2)$$

Resource potential zone mapping: In this study, AHP method was used, and thematic layers were assigned weights to detect resource potential zones. Using ArcGIS10.8, all the layers were converted into raster format and multiplied with derived weights and rank. The resource potential is evaluated by integrating all layers in ArcGIS from weighted overlay analysis method and categorizing the results into five classes using natural breaks (Jenks optimization method), namely very poor, poor, moderate, good and excellent to produce the final RPZ map (Eq. (3)).

$$RPZ = \sum [GG_W GG_R + DD_W\ DD_R + SL_W SL_R + RF_W RF_R + S_W S_R + LULC_W LULC_R + E_W E_R] \qquad (3)$$

Where, W and R - represents weight and rank respectively of each parameter, GG Geology, DD Drainage Density, SL Slope, RF Rainfall, S Soil, LULC Land Use Land Cover, E Elevation. The resource potential zone values were classified into five zones: excellent potential, good potential, moderate potential, low potential and very low potential zone.

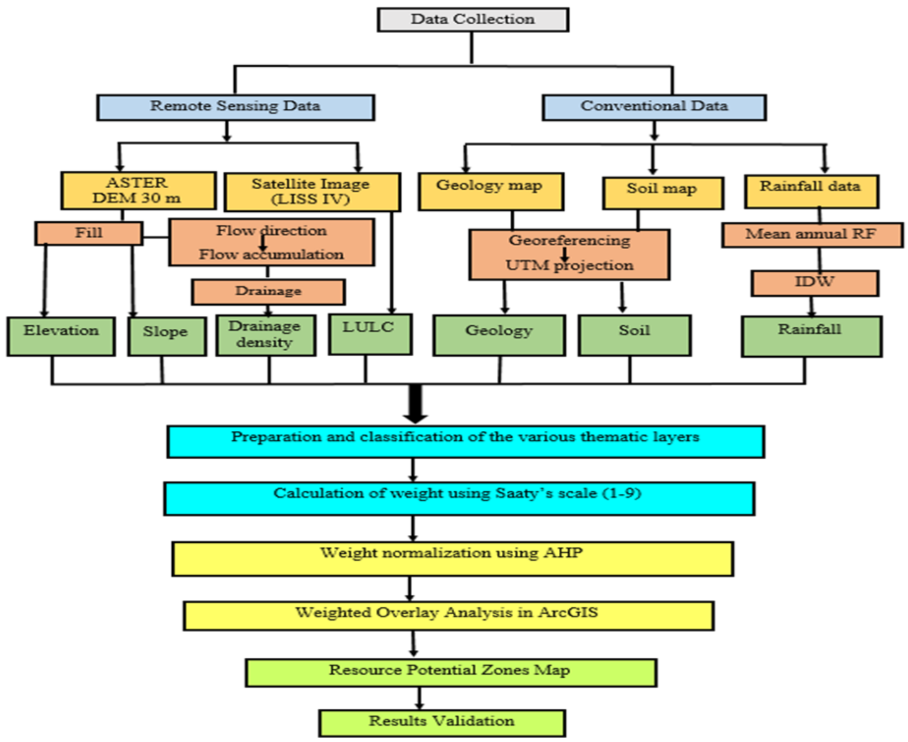


Fig. 2: Flowchart of the methodology

Objective 2: Assessment of physiochemical parameters of soil and water in the watershed.

- Based on the field survey, literature review and visit done in HNB Garhwal University, discussion with different department, faculty members and research scholars of the HNB Garhwal University and interaction with the local people and the site observation were used to finalize the sampling locations. Soil and water samples were collected seasonally i.e. pre monsoon, monsoon and post monsoon (Table 1) and physico-chemical analysis was done in the laboratory as per standard methodology.

Table 1: Details of sampling season and sampling period

Sampling Season	Sampling Period
Pre-monsoon	Mid-week of April 2019 and 2022 (Due to Covid 19 pandemic restrictions in year 2020 and 2021 pre monsoon sampling could not be done)

Monsoon	First week of September (2019-2021)
Post-monsoon	Last week of October (2019-2021)

(i) Details of sampling sites and collection of soil samples: The soil samples were collected from different land use patterns at different latitudes i.e lower altitude (600-900 meter, middle latitude (900-1200 meter) and higher altitude (1200-1500meter) in Takoli Gad watershed, Tehri Garhwal, Uttarakhand. Through composite sampling depth wise viz. 0-10 cm, 10-20 cm and 20-30 cm samples were collected from selected sites (Table 2).

Table 2: Details of sampling sites of soil in Takoli Gad watershed

No. of sites	**Sites**	**Elevation**	**Latitude**	**Longitude**
Lower altitude between 600-900 meter				
1	Dhangchora Pali			
1 A)	Settlement	639m	N30^{0}17’30.49”	E078^{0}42’15.72”
1 B)	Agriculture	622m	N30^{0}15’19.85”	E078^{0}42’15.72”
1 C)	Forest	630m	N30^{0}15’20.80”	E078^{0}43’09.35”
1 D)	Waste Land	665m	N30^{0}20’14.15”	E078^{0}41’50.09”
Middle altitude between 900-1200 meter				
2	Neuli			
2 A)	Settlement	1180m	N30^{0}18’.00.01”	E078^{0}42’01.02”
2 B)	Agriculture	1183m	N30^{0}18’00.09”	E078^{0}42’.01.87”
2 C)	Forest	1139m	N30^{0}17’54.18”	E078^{0}42’04.69”
2 D)	Waste Land	1185m	N30^{0}18’00.63”	E078^{0}42’03.77”
Higher altitude between 1200-1500 meter				

3	Jakhi Dagar			
3 A)	Settlement	1258m	N30^{0}19’36.01”	E078^{0}43’27.33”
3 B)	Agriculture	1262m	N30^{0}19’36.49”	E078^{0}43’28.65”
3 C)	Forest	1264m	N30^{0}19’35.44”	E078^{0}43’26.58”
3 D)	Waste Land	1264m	N30^{0}19’35.15”	E078^{0}43’27.60”

(ii) Details of sampling sites and collection of water samples: The water samples were collected from natural spring of Takoli Gad watershed, Tehri Garhwal district, Uttarakhand. On the basis of best suitability, perennial nature and feasible spring sites, elevation and dependency of the local people on the natural spring water for domestic purpose (Table 3).

Table 3: Details of sampling sites of springs in Takoli Gad watershed

No. of Sites	Sampling site name	Elevation	Latitude	Longitude
1	Dhangchura Spring 1	661m	N30^{0}15’18.25”	E078^{0}43’09.46”
2	Dhangchura Spring 2	656m	N30^{0}15’18.34”	E078^{0}43’09.54”
3	Malupani Spring	785m	N30^{0}17’23.38”	E078^{0}42’09.99”
4	Takoli Spring	803m	N30^{0}17’59.74”	E078^{0}40’55.11”
5	Dhaulangi Spring	1115m	N30^{0}20’06.49”	E078^{0}38’17.07”
6	Pendula Spring	941 m	N30^{0}19’38.41”	E078^{0}39’10.45”
7	Amroli Spring	924m	N30^{0}8’05.18”	E078^{0}41’37.71”
8	Semi Semla Spring	999m	N30^{0}17’48.57”	E078^{0}42’55.38”
9	Katal Spring	993m	N30^{0}18’05.26”	E078^{0}41’37.82”
10	Neuli Spring	1111m	N30^{0}17’53.90	E078^{0}42’04.59”
11	Khanndu Spring	1270m	N30^{0}19’35.44”	E078^{0}43’27.28”

12	Belta Spring 1	1116m	N30^{0}20’35.71”	E078^{0}41’59.33”
13	Belta Spring 2	1257m	N30^{0}20’44.18”	E078^{0}41’49.94”
14	Belta spring 3	1238m	N30^{0}30’44.24”	E078^{0}41’50.00”

Water sample collection from natural springs, TakoliGad watershed

Objective 3: Watershed integrity index of the studied area.

Objective entitled “Watershed Integrity Index of the Takoli Gad watershed” will be the part of the PhD thesis. This objective will be compiled in the PhD thesis work.

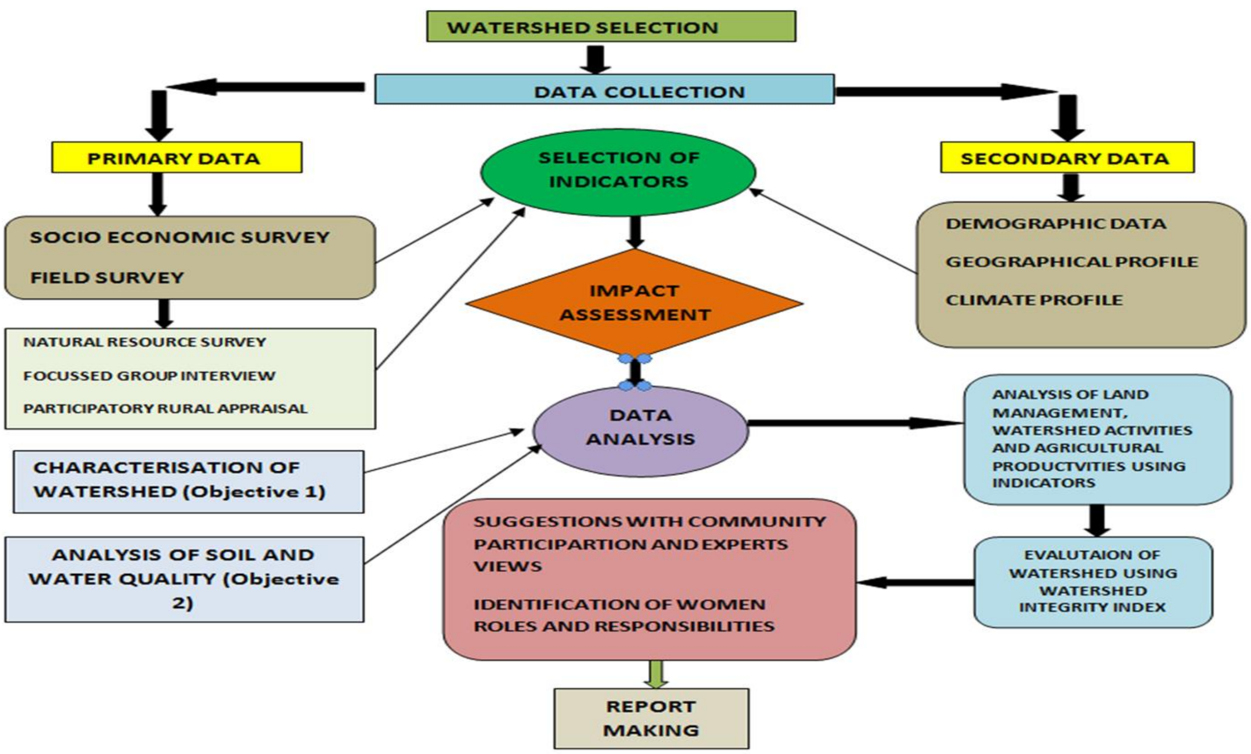


Fig. 3: Flowchart of methodology adopted for watershed integrity index

Objective 4: Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability

Structured type questionnaire was prepared for defining the village socio economic profile. Interview and informal discussions were conducted. Respondents were selected from different sex, age group, educational, social and economic classes by random stratified sampling.

- Secondary data has been collected from Block Division Office, Kirti Nagar Block for Takoli Gad watershed, Tehri District
- Field surveys were done.
- A focused group interview was conducted.

2.2 Details of scientific data collected and equipments used

Detailed description of the scientific data collected, methods and equipments used for the assessment of the physiochemical parameters of soil and water in the Takoli Gad watershed (Table 4,5). The scientific data is collected seasonally (pre monsoon, monsoon and post monsoon).

Table 4: Detail of the methods and equipment used for physicochemical analysis

S.No.	Parameters	Method for water	Method for soil	Instruments
1	pH	pH meter	pH meter	pH/EC/TDS meter (multi parameter PC Testr 35)
2	EC	EC meter	EC meter	pH/EC/TDS meter (multi parameter PC Testr 35)
3	TDS	TDS meter	-	pH/EC/TDS meter (multi parameter PC Testr 35)
4	Total Alkalinity	Titrimetric method	-	-
5	Total Hardness	EDTA (Titrimetric method)	-	-
6	Calcium	EDTA (Titrimetric method)	-	-
7	Magnesium	Calculation	-	-

8	Sodium	Flame photometric method	-	Atomic Absorption Spectroscopy
9	Potassium	Flame photometric method	Ammonium Acetate method	Atomic Absorption Spectroscopy
10	Chloride	Argentometric Titration	-	-
11	Sulphate	Turbidimetric method	-	UV Spectrophotometer (Spectroquant PROVE-600)
12	Bicarbonates	Titrimetric method	-	-
13	Nitrate	Spectrophotometric method	Phenoldisulphonic acid method	UV Spectrophotometer (Spectroquant PROVE-600)
14	Available Phosphorous	-	Olsen's method	UV Spectrophotometer (Spectroquant PROVE-600)
15	Organic Carbon	-	Walkely & black method	-
16	Bulk Density	-	Weighing Bottle method	-
17	Soil Moisture Content	-	Gravimetric method	-
18	Total Nitrogen	-	Kjeldahl method	Kjeldahl unit
19	Available Sulphur	-	Calcium cholride-Extractable S method	UV Spectrophotometer (Spectroquant PROVE-600)

20	Essential micronutrients (Fe, Zn, Mn and Cu)	-	DPTA method	Atomic Absorption Spectroscopy

Table 5: Details of the scientific data collected for resource potential mapping

Parameters	Data source
Elevation (m)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model
Slope (^{O})	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model
Drainage Density (km/km^2)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model
Land use and land cover	Indian Remote Sensing Satellite (IRS) LISS IV data of February, 2020
Geology	Bhukosh, Geological Survey of India
Soil	NRSA-Indian Institute of remote sensing
Rainfall (mm)	CRU (Climatic Research Unit) 4.06 Global Climate Database

2.4 Details of field survey arranged

Primarily, reconnaissance survey was conducted to assess the status of the watershed in terms of physical, biological, economic and social factor. Based on the field survey, literature review, interaction with the local people and the site observation were used to finalize the sampling locations for soil and spring water. The samples of soil and spring water were collected in the different season i.e. pre monsoon period, monsoon period and post monsoon period for consecutively three years. The soil samples were collected from different land use patterns at different latitudes i.e. lower altitude (600-900 meter, middle latitude (900-1200 meter) and higher altitude (1200-1500meter) in Takoli Gad watershed, Tehri Garhwal, Uttarakhand. Through composite sampling depth wise viz. 0-10 cm, 10-20 cm and 20-30 cm samples were collected from selected sites. The water samples were collected from natural spring of Takoli Gad watershed, Tehri Garhwal district, Uttarakhand. On the basis of best suitability, perennial nature and feasible spring sites, elevation and dependency of the local people on the natural spring water for domestic purpose. The physico-chemical analysis for the different parameters of water and soil were performed as prescribed in the APHA guide manual (APHA, 2012) and Indian Council of Agricultural Research Manual (2011) by Ministry of Agriculture accordingly. Water discharge of the selected springs was also measured for the different seasons. Frequent and detailed field surveys were conducted including land use pattern, irrigation status, soil type, demographic details including the literacy status, livestock details, cropping pattern, different occupations of the households, availability of credits from institutions, access to drinking water, functioning of SHGs, the availability of institutions or infrastructure in the habitants. Focused group interviews using common questionnaire with women and men were organized separately regarding the issues related to women particularly in terms of workload, decision making, access to information and earnings. The survey involved 400 respondents were randomly chosen and interviewed from different vikas khand area of the Takoli Gad watershed. Participatory Rural Appraisal (PRA) activities based on random sampling method were conducted in the Takoli Gad watershed for resource estimation as well as surveys related to analysis of developmental activities and policies implementation.

2.5 Strategic Planning for each Activities

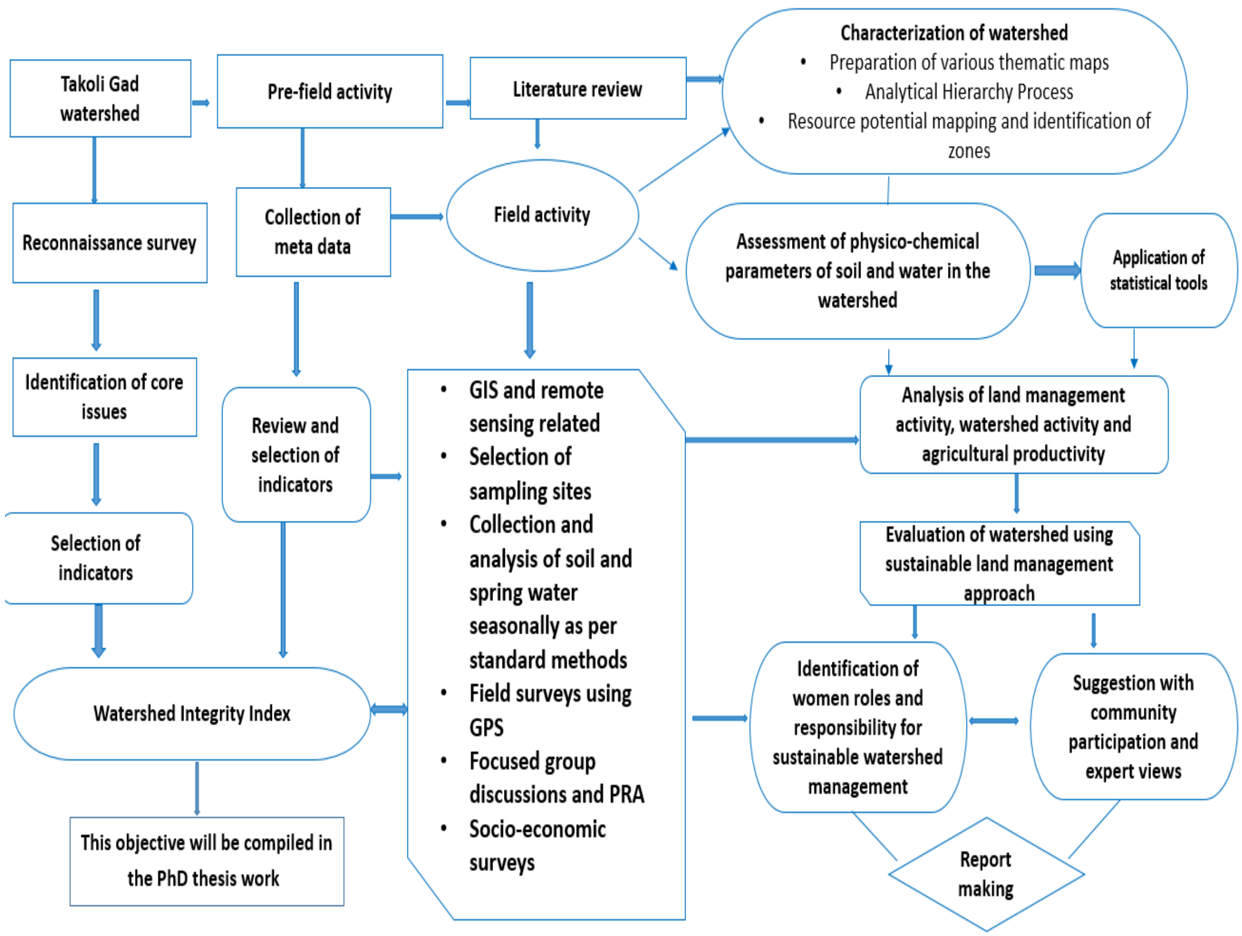


Fig 4: Strategic Planning for each Activities

2.6 Activity-wise Timeframe followed using Gantt/Pert Chart

S.No.	Activities	1st year				2nd year				3rd year			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Collection and collation of literature												
2	Reconnaissance survey to assess the status of												

	available natural resources in the study area												
3	Selection of sampling sites for physico-chemical analysis of soil and water												
4	Collection and analysis of physico-chemical parameters												
5	Collection of primary and secondary data characterization of watershed												
6	Data evaluation and resource potential mapping using various methodology												
7	Field surveys, Focused group interviews, participatory rural appraisal regarding the issues related to women particularly in terms of workload, decision making, access to information and earnings												
8	Collection of secondary data regarding demographic details including the literacy status, livestock details, cropping pattern, different												

	occupations of the households												
9	Data evaluation and interpretation												
10	Identification of the indicators that are used to develop watershed integrity index of the study area												
11	Identification of the roles played by women in watershed management												
12	Final report submission												

3 KEY FINDINGS AND RESULTS

3.1 Major Research Findings

Objective 1: Characterization the watershed on the basis of available resources

Morphometric Characteristics: Based on the drainage map, survey of India topographic map, remotely sensed data morphometric analysis for the present study is estimated (Table 6 and 7). According to Strahler stream ordering method (Strahler 1952; Arbar et al., 2021) the Takoli Gad has fifth order stream order (Fig. 5). The value of the bifurcation ratio (Rb) is 5.46 which means the characteristics of the watershed suffered structural disturbances (Patil and Mali, 2013). The drainage density of the watershed is 1.66 km/km^2 which means the area is coarse texture which occurs in regions with high permeable sub soil under dense vegetation cover (Panhalkar et al., 2012; Sindhu et al., 2015). The elongation ratio obtained is 0.86 which indicates that the catchment is oval in shape (Rai et al., 2018). The circulatory ratio value of the study area is 0.75 which indicated that the basin is less elongated in shape (Prasannakumar et al., 2013). The lowest relief value is 505m and highest relief value is 2496m. The total basin relief of the catchment is 1991m which indicates that the basin is having high relief and steep slope topography which causes more runoff in the basin (Singh et al., 2021). Ruggedness number value is 3.31 which indicates that the study area is having moderately prone to erosion (Sindhu et al., 2015).

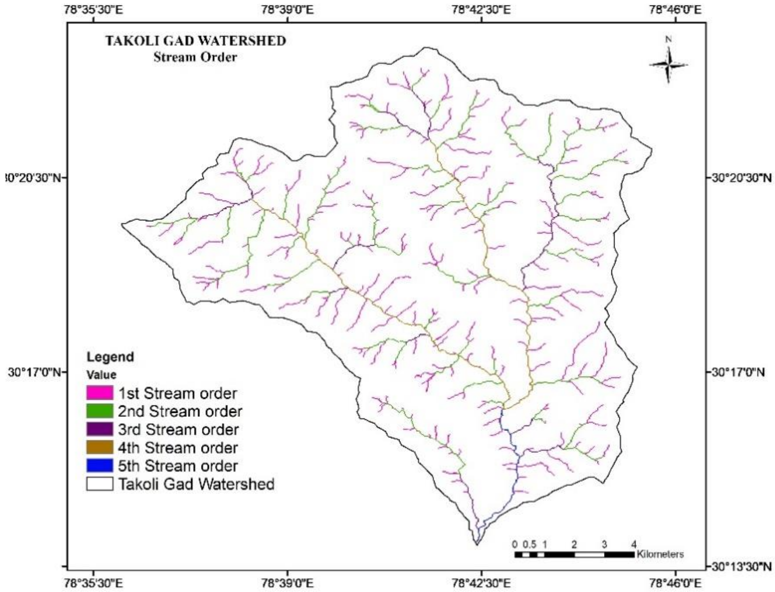


Figure 5: Stream order map of Takoli Gad watershed

Table 6: Computed linear morphometric aspects of Takoli Gad watershed

Takoli Gad water shed	Stream Order (U)					Stream Length (Lu) (km)				
	I	II	III	IV	V	I	II	III	IV	V
	377	115	20	11	1	109.817	63.282	23.096	19.651	5.56

Takoli Gad watershed	Bifurcation ratio (Rb)				Mean bifurcation ratio (Rbm)
	I/II	II/III	III/IV	IV/V	
	3.27	5.75	1.81	11	5.46

Table 7: Computed Areal and relief aspect of the Takoli Gad watershed

Parameters	Takoli Gad watershed

Basin perimeter (P) (km)	47
Basin area (A) (km^2)	133
Basin Length (Lb) (km)	15.141
Circulatory ratio (Rc)	0.757
Elongation Ratio (Re)	0.860
Drainage density (Dd)	1.665
Lowest relief (R) (m)	505
Highest Relief (r) (m)	2496
Basin relief (H) (m)	1991
Ruggedness index (Ri)	3.314

Multi-criteria decision analysis:

The consistency ratio (CR) in this study is determined to be 0.095; which indicates an acceptable level of consistency in the pair-wise comparison phase (Table 8,9,10). As a result, it is evident that the AHP model used in this study indicated reasonably good accuracy in spatial predicting the probability of resources.

Table 8. The rating scale (1-9) of Saaty's AHP (Saaty 1990)

Strength of Significance	Explanation
1	Equal significance
3	Medium significance
5	Strong
7	Very strong significance
9	Maximum Significance
2,4,6,8	Interim number between two adjacent numbers

Table 9. The RI ratio of the distinct values of n (Saaty, 1990)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.89	1.12	1.25	1.32	1.40	1.45	1.49

Table 10. The pair-wise comparison matrix and normalized weight (w_i) of the different themes

Theme	GG	DD	SL	RF	S	LULC	E	Normalized weight (w_i)
GG	1	3	5	5	7	5	8	0.391
DD	1/3	1	3	5	5	7	8	0.238
SL	1/5	1/3	1	1	3	1	7	0.103
RF	1/5	1/3	1	1	3	5	6	0.125
S	1/7	1/5	1/3	1/3	1	3	5	0.069
LULC	1/5	1/7	1	1/5	1/3	1	3	0.052
E	1/8	1/8	1/7	1/6	1/5	1/5	1	0.022
Total	2.19	5.12	11.47	10.69	19.53	22.33	38	100

$\Lambda_{max} = 7.756$ CI = 0.126 RI =1.32 CR = 0.095

GG Geology, DD Drainage Density, SL Slope, RF Rainfall, S Soil, LULC Land Use Land Cover, E Elevation, Λ_{max} Principal Eigen value, CI Consistency Index, RI Random Index, CR Consistency Ratio

Thematic maps

Elevation, slope, geology, soil, rainfall, land use land cover, and drainage density are the seven parameters those are thoroughly analyzed to evaluate the resource potential zones of the study area. The relative influence value (Fig 5) and AHP weight calculated for resource potential are mentioned in Table 11.

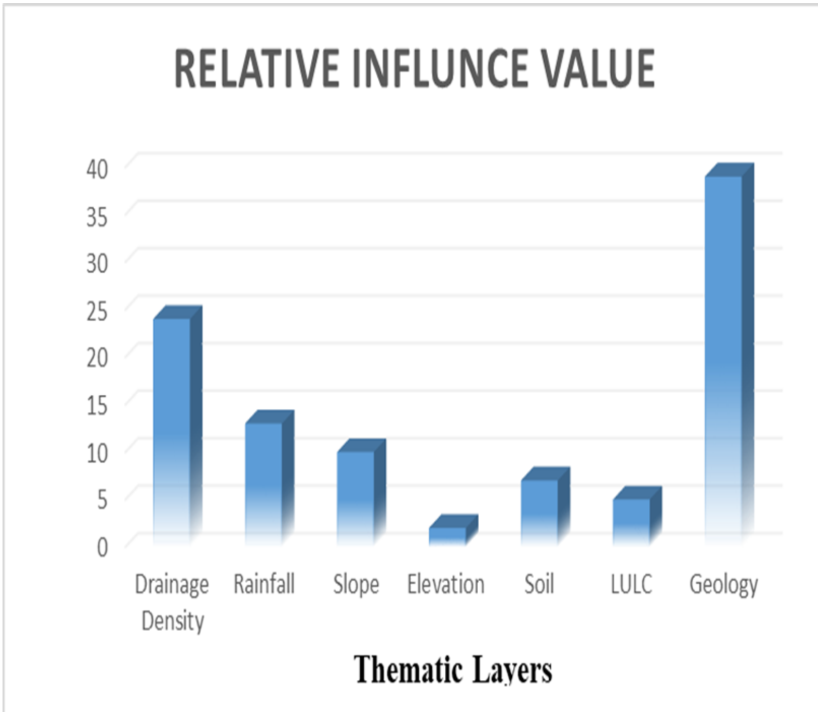


Fig 5: Relative influence value

Table 11. AHP weight for calculating resource potential.

Thematic class	Sub class	AHP weight	Relative Influence value	Scale value (0-5)
Drainage Density	0-0.578	0.238	24%	5
	0.579-1.285			4
	1.286-1.958			3

	1.959-2.698			2
	2.699-4.096			1
Rainfall	1829-1837mm	0.125	13%	1
	1838-1846mm			2
	1847-1854mm			3
	1855-1862mm			4
	1863-1870mm			5
Slope	0.301-17.868	0.103	10%	5
	17.869-26.513			4
	26.514-34.042			3
	34.043-42.128			2
	42.149-71.407			1
Elevation	505-971	0.023	2%	5
	972-1240			4
	1241-1520			3
	1521-1848			2
	1849-2496			1
Soil	Dystric Eutrochrepts	0.069	7%	4
	Typic Udorthents			5
	Barren land			1
	Agriculture			5
	Very dense forest			5

LULC	Moderately dense forest	0.052	5%	4
	Open forest			3
	Scrub land			2
	Settlement			1
Geology	Phyllite	0.391	39%	5
	Basic meta-volcanics			3
	Sand, silt and clay			4
	Phyllite, Qtz, Shale			4
	Limestone and shale			3
	Quartzite			1

Elevation

Mapping of water resource potential has been significantly influenced by elevation (Hasanuzzaman et al., 2022). Water flows downward from higher to lower elevations. Lower elevated area was assigned a higher weight while highly elevated areas were assigned a lower weight (Abrar et al., 2021). Takoli Gad watershed elevation ranges from 505 m to 2496m from mean sea level (Fig. 6). Further, it was classified into five sub classes i.e. 505 – 971 m (26.18 km^2), 972 – 1240 m (34.37 km^2), 1241- 1520 m (33.06 km^2), 1521 – 1848 m (25.06 km^2) and 1849 – 2496 m (14.33 km^2).

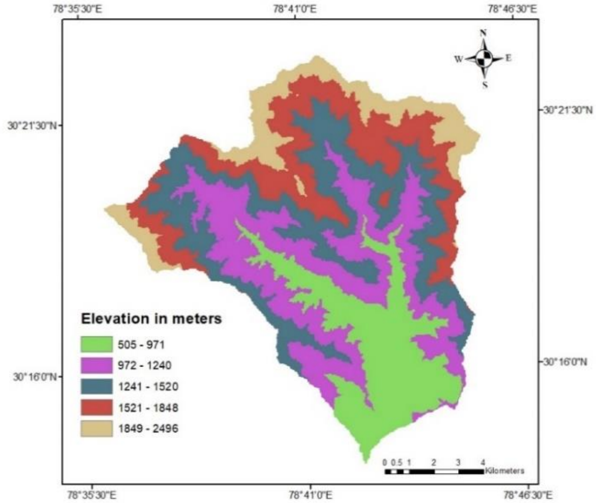


Figure 6: Elevation map of Takoli Gad watershed

Slope

Slope is an important parameter in determining water resource potential zones (Jhariya et al., 2021). In the mapping process of resource potential zones, very steep slopes were assigned the least weights, while less steep slope were assigned more weights. Steeper slope considered as poor recharge zones which causes rapid surface runoff and less infiltration rates (Vasileva, 2019; Abhijit et al., 2020; Saranya and Saravanan, 2020). The slope map (Fig. 7) of the Takoli Gad watershed shows hilly regions which ranges from 0.30^0 to 71.41^0 and is classified into five sub classes such as gentle (15.92 km^2), moderate (31.76 km^2), strong (39.31 km^2), steep (32.31km^2) and very steep slope (13.70 km^2).

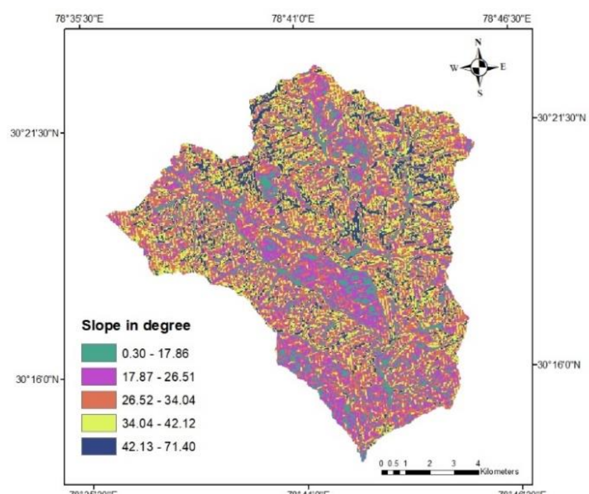


Figure 7: Slope map of Takoli Gad watershed

Geology

Among all the aspects, geology is considered as the one of the leading factor by controlling the water percolation which has an impact on resource potential zones (Vasileva, 2019). Phyllite, Basic meta-volcanics, Sand, silt and clay, Shale, Limestone and shale, Quartzite are the different geological formation discovered in the Takoli Gad watershed (Fig. 8) which controls the infiltration of water. The area with sand and sandy clay is a percolation zone due to its high porosity and high permeability (Suganthi et al., 2013, Arulbalaji et al., 2019). Phyllite rock is permeable and undergone high weathering (Saraf et al., 2018; Biswakarma et al., 2020) due to its highly foliated structures. Basic meta-volcanics are good aquifer as it is highly weathered and fractured (Senanayake et al., 2016). Quartzite is a hard rock, which generally does not have primary porosity. Secondary porosity in the form of fractures and weathering only allow groundwater occurrence. These rocks have low porosity (Rajaveni et al., 2017). A weightage of 0.39 was assigned to this layer.

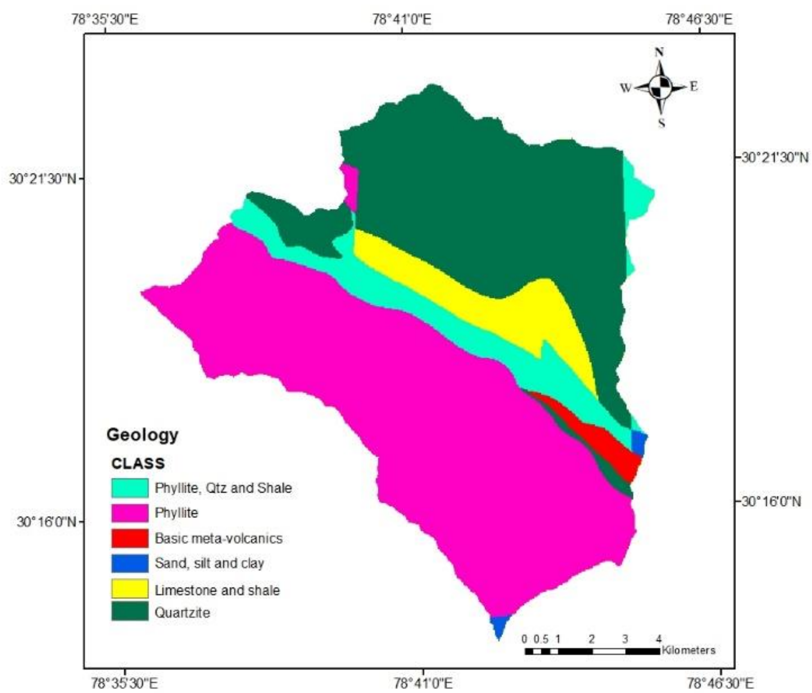


Figure 8: Geology map of Takoli Gad watershed

Soil: The Takoli Gad watershed contains two soil categories that is Dystric Eutrudepts and Typic Udorthents. Dystric Eutrudepts are relatively shallow, well drained, thermic, fine loamy, slightly rocky. Typic Udorthents are moderately shallow, excessively drained, moderate erosion, slightly stony and loamy and sandy skeletal soil. The soil type categories were assigned weight according to the drainage classes which implies the duration of wetness (Vasileva, 2019; Abhijit et al., 2020; Saranya and

Saravanan, 2020; Doke et al., 2021). Mostly the area is covered by typic udorthents soil (Fig. 9). A weightage of 0.069 was assigned to this layer.

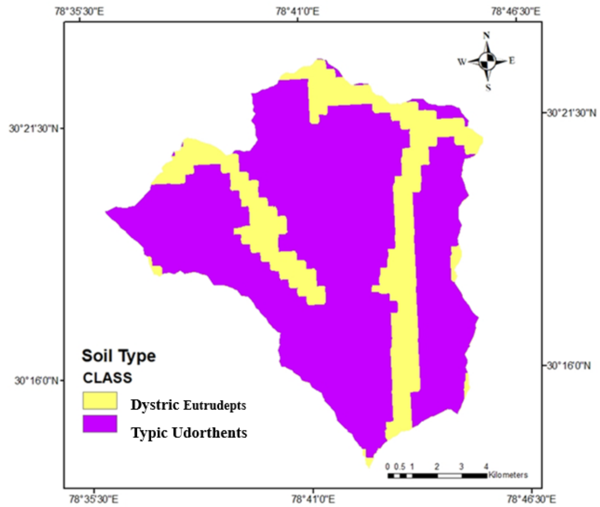


Figure 9: Soil map of Takoli Gad watershed

Drainage density

The drainage density (km^{-1}) defines as the total stream length divided by the total basin area (Arulbalaji et al., 2019; Abhijit et al., 2020). Low drainage density indicates permeable regions with dense vegetation cover and low relief while higher drainage density indicates regions with weak and impermeable subsurface material, sparse vegetation and high relief (Borah and Deka, 2020). More weightage was assigned to area with very low drainage density, while less weightage was assigned to areas with very high densities due to increased surface runoff (Suganthi et al., 2013; Bathis and Ahmed, 2016; Vasileva, 2019). Drainage density (Fig. 10) is classified into 5 sub classes which ranges from 0 – 0.578 km/km^2 (33.28 km^2), 0.579 – 1.285 km/km^2 (30.49 km^2), 1.286 – 1.958 km/km^2 (32.25 km^2), 1.959 – 2.698 km/km^2 (23.85km^2) and 2.699 – 4.096 km/km^2 (13.13 km^2). A weightage of 0.0238 was assigned to this layer.

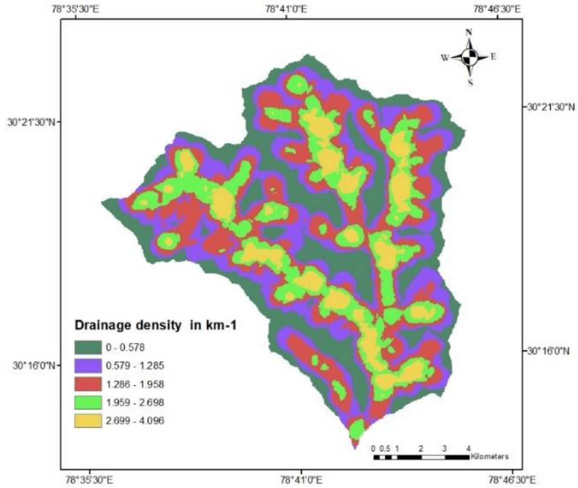


Figure 10: Drainage density map of Takoli Gad watershed

Land use and Land cover

Land use provides the precise and accurate information for managing water resources sustainably. Land use pattern influences the infiltration and permeability process (Arulbalaji et al., 2019; Owolabi et al., 2020; Doke et al., 2021). Takoli Gad watershed (Fig. 11) has been divided into seven key categories including barren land (1.18 km^2), agriculture (24.48 km^2), very dense forest (15.71 km^2), moderately dense forest (38.91 km^2), and open forest (47 km^2), scrub land (2 km^2), settlement (3.72 km^2). Dense forest has greater water holding capacity thus improve the water recharge system, a higher score was assigned to forest and vegetation cover. Scrublands have thin and very shallow soils that are slightly suitable for groundwater recharge. As a result, moderate score was assigned to scrublands. Because of thin soil, the surface runoff rate is higher on the barren land therefore, lower score is assigned. The agricultural land is preferred for groundwater recharge due to loose soils influence water to infiltrate to the subsurface. The maximum score was given to the agricultural land. The settlement area which is made of concrete, the surface runoff is high and the infiltration rate is lower. As a result, very low score was assigned to settlement land (Doke et al., 2021, Jhariya et al., 2021). A weightage of 0.052 was assigned to this layer.

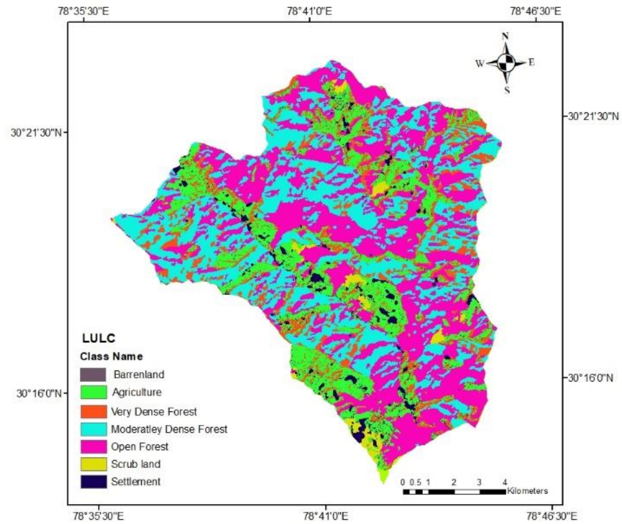


Figure 11: Land use land cover map of Takoli Gad watershed

Rainfall

Rainfall is the key component of hydrogeological cycle and main source of recharge (Abhijit et al., 2020; Saranya and Saravanan, 2020). Rainfall distribution along with the slope gradient, has a direct impact on the runoff water infiltration, increasing the possibility of water resource potential zones. Because rainfall has a positive influence on water recharge, the regions with higher rainfall range are ranked higher whereas the regions having lower rainfall are ranked lower (Owolabi et al., 2020). The mean average annual rainfall (Fig. 12) of the Takoli Gad watershed ranges from 1829 mm to 1870 mm. The rainfall map is grouped into five sub classes such as 1829 to 1837 mm (20.31 km^2), 1838 to 1846 mm (42.66 km^2), 1847 to 1854 mm (39.44 km^2), 1855 to 1862 mm (22.56 km^2) and 1863 to 1870 mm (8.03 km^2). A weightage of 0.125 was assigned to this layer.

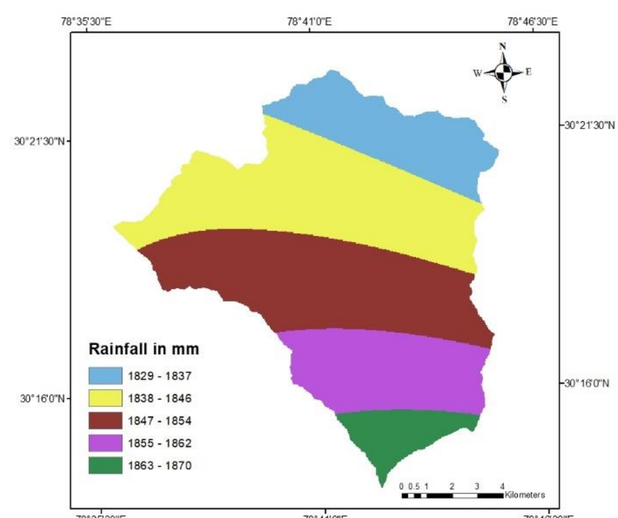


Figure 12: Rainfall map of Takoli Gad watershed

Resource potential zone mapping

The resource potential zone values were classified into five zones: excellent potential, good potential, moderate potential, low potential and very low potential zone (Fig. 13). The results (table 9) of this study shows that only 1.59 % (2.12 km^2) of the region exhibit excellent potential zone, 45.21 % (60.12 km^2) moderate potential zone, 25.61% (34.06 km^2) good potential zone, 26.41 % (35.13 km^2) poor potential zone and 1.18 %(1.57 km^2) very poor potential zone (Table 12). The western and southern part of the study area showed with moderate to excellent resource potential zones. The poor and very poor potential region is found in the most part of northern and part of eastern region of the watershed.

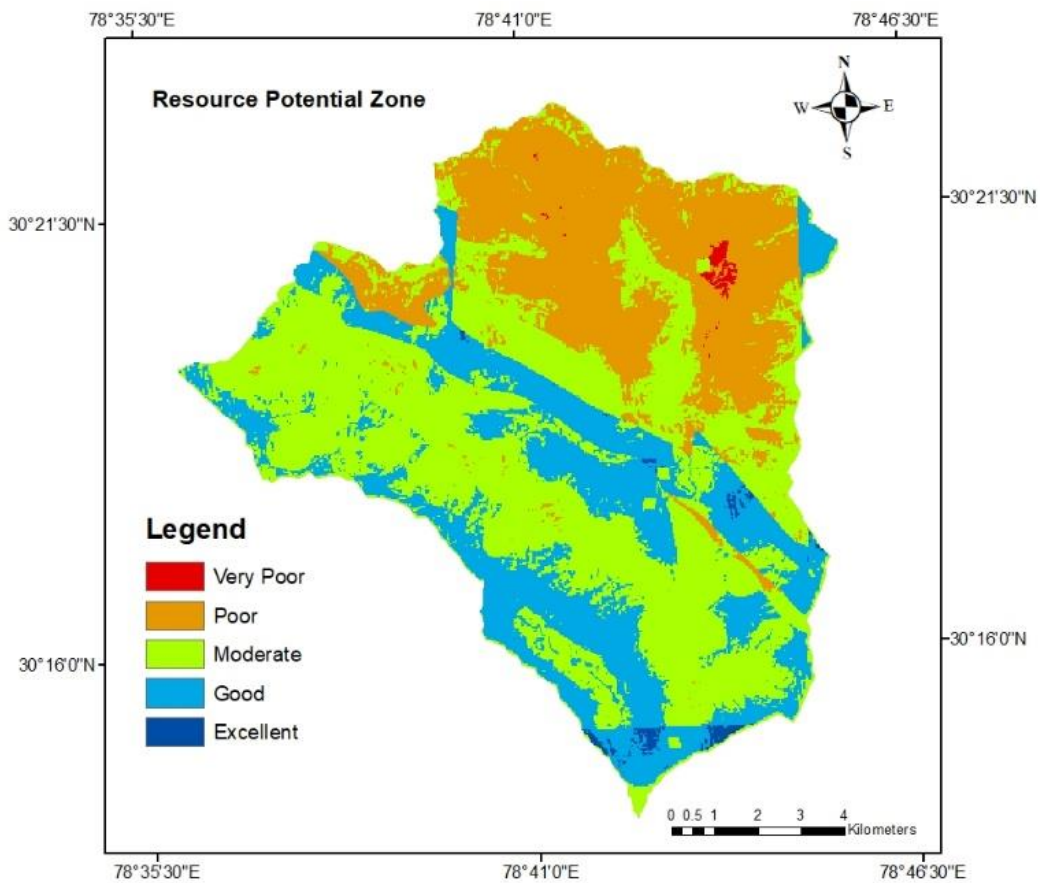


Figure 13: Resource Potential map of Takoli Gad watershed

Table 12. Classification of resource potential zones (after integration of all thematic maps)

Resource Potential Zones	Area (%)	Area (km^2)
Very poor	1.18	1.57
Poor	26.41	35.13
Moderate	45.21	60.12
Good	25.60	34.06
Excellent	1.59	2.12
Total	100	133

Objective 2: Assessment of physiochemical parameters of soil and water in the watershed.

Water quality analysis is important for present conditions can be useful in the same ecological conditions at the future review to accessibility of safe drinking water. Seasonal changes are usually defined by the precipitation and temperature at various times over the year. The whole monitoring period was divided into three seasons, namely, pre monsoon, monsoon and post monsoon. Samples were collected in 1000 ml in High-Density Poly Ethylene water bottles through each sampling sites from April, 2019 to April, 2022. Thereafter, immediately these samples were analyzed for pH and EC using handheld pH-EC meter, while other parameters analyzed in the laboratory. The results (Table 13) showed that most of the physiochemical parameters were within drinking water standards.

Table 13: Physiochemical parameter analysis of spring water

Parameters	Pre monsoon		Monsoon		Post monsoon	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
pH	7.15	0.37	7.41	0.41	7.87	0.41
EC	344.5	98.27	421	151.62	343.03	127.90
TDS	279.14	83.90	293.85	105.33	267.96	91.30
Total Hardness	106	83.90	197.85	60.02	216.14	79.85
Alkalinity	138.21	53.29	412.5	96.92	295.35	75.20
Ca^{2+}	64.85	17.38	135.35	44.14	126.64	44.29
Mg^{2+}	41.14	28.93	62.5	22.70	89.5	39.58
Na^{+}	9.18	4.37	13.04	6.65	9.18	4.3723
K^{+}	0.91	0.53	1.82	1.14	1.40	0.88

Cl^-	12.34	4.16	32.18	12.48	35.32	10.23
HCO_3^-	216.92	90.37	105.42	16.96	312.35	72.76
NO_3^-	16.37	8.64	5.04	3.79	10.37	8.09
SO_4^{2-}	28.12	11.66	10.30	3.10	22.30	11.24

Correlation matrix of the physico-chemical parameters

In order to study the relationships among multiple variables through Pearson's correlation matrix. The strength of the association between two or more variables is explained with weak ($r<0.500$) and strong ($r \geq 0.500$) correlations. EC was strong and positively correlated with TDS ($r = 9.17$), TH ($r = 7.14$), Ca^{2+}($r = 0.755$) and Na^+ ($r = 0.764$) found to be significant at $p<0.01$ level. Similarly, TH shows strong and positive correlation with Ca^{2+} ($r = 0.944$) and Mg^{2+}($r = 0.899$), significant at $p<0.01$ which supports the occurrence of temporary hardness.

Parameter	**pH**	**EC**	**TDS**	**TH**	**Ca^{2+}**	**Mg^{2+}**	**TA**	**Cl**	**Na^+**	**K^+**	**HCO_3^-**	**SO_4^{2-}**	**NO_3^-**
pH	1												
EC	.166	1											
TDS	.114	**.917****	1										
TH	.461**	**.714****	**.608****	1									
Ca^{2+}	.396**	**.755****	**.637****	**.944****	1								
Mg^{2+}	.466**	**.535****	.463**	**.899****	**.706****	1							
TA	.324*	**.684****	**.538****	**.788****	**.871****	**.540****	1*						
=Cl	.284	.411**	.341*	**.761****	**.739****	**.658****	**.698**	1**					
Na^+	-.072	**.764****	**.693****	**.580****	**.641****	.398**	**.610**	**.545****	1**				
K^+	.102	**.521****	.407**	**.538****	**.538****	.444**	**.580**	**.501****	.342**	1**			
HCO_3^-	.311*	.113	.210	.302	.124	.487**	-.143*	.198	.070	-.130	1		
SO_4^{2-}	-.332*	.002	**.064**	-.004	-.165	.212	-.399*	-.051	.082	-.038	.425	1	
NO_3^-	-.396**	-.111	-.041	-.164	-.277	.014	-.405**	-.184	-.043	-.231	.314	**.739**	1**

**. Correlation is signification at the 0.01 level (2- tailed)

*. Correlation is signification at the 0.05 level (2- tailed)

Water Quality Index (WQI): WQI is an algorithm that represents the qualitative condition of the water. Water quality index shall be considered from the perspective of groundwater suitability for human consumption. Horton (1965) developed the weighted arithmetic water quality index; using physicochemical parameters as contributions to a series of equations (Table 14). WQI values are ordered into five classifications: excellent water (WQI, 0-25); good water (WQI, 26-50); poor water (WQI, 51–75); very poor water (WQI, 76–100); and water unsuitable for drinking (WQI, >100) (Chandra et al., 2017).

Table 14: Relative weight of chemical parameters:

Chemical Parameters	**Units**	**BIS (2012)**	**Weight (*wi*)**	**Relative weight Wi= wi/$\sum^{n}_{i=1}$Wi**
pH	-	6.5-8.5	2	0.046512
TDS	mg/L	500	3	0.069767
TA	mg/L	200	3	0.069767
TH	mg/L	200	5	0.116279
Ca^{2+}	mg/L	75	5	0.116279
Mg^{2+}	mg/L	30	5	0.116279
Na^{+}	mg/L	200	3	0.069767
K^{+}	mg/L	12	3	0.069767
Cl^{-}	mg/L	250	2	0.046512
HCO_3^{-}	mg/L	244	3	0.069767
SO_4^{2-}	mg/L	200	4	0.093023
NO_3^{-}	mg/L	45	5	0.116279
			∑wi= 43	**∑Wi= 1**

Suitability of spring water for Water Quality Index (WQI):

From WQI, spring water can be ordered into five classes based on WQI values. According to the categorization (Table 15), out of total samples analyzed 28% spring samples comes under excellent water class, 72% samples has a place with good water class for Pre monsoon season , while 7 % of samples belongs to excellent water category where as 57 % samples were found of good water category and 36 % samples were found under poor water category for monsoon season and 64 % samples belongs to good water category and 36 % samples were found under poor water category for post monsoon season (Chandra et al., 2017). The spatial patterns of WQI for the study region are illustrated in figure 14-16. Pre monsoon season shows that the majority part of the study area comes under the second category (good), with the exception of a small patch in the North West region under the excellent category. Monsoon season sows that only one spring Kanndu comes under the excellent water category while good category region get decreases in relation with pre monsoon season and poor water category found on the western region and lower southern part of the watershed. The POSTMON season shows that no excellent category area seen in the watershed while good category covers about all regions of the watershed except for middle and southern region where poor water category region is observed.

Table 15: WQI classification (Chandra et al., 2017)

Water quality index level	Water quality status	Pre Monsoon		Monsoon		Post Monsoon	
		No. of samples	% of samples	No. of samples	% of samples	No. of samples	% of samples
<50	Excellent water quality	4	28	1	7	-	-
50-100	Good water quality	10	72	8	57	9	64
100-200	Poor water quality	-	-	5	36	5	36
200-300	Very poor water quality	-	-		-		-
>300	Undesirable for drinking	-	-		-		-
Total		**14**	**100**	**14**	**100**	**14**	**100**

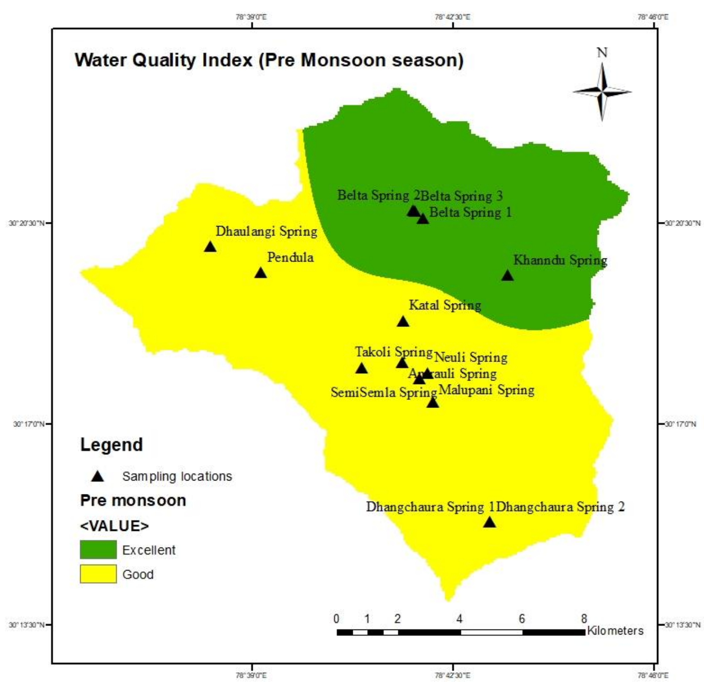


Fig. 14: Spatial distribution maps of water quality index (WQI) in the Takoli Gad Watershed for Pre monsoon season

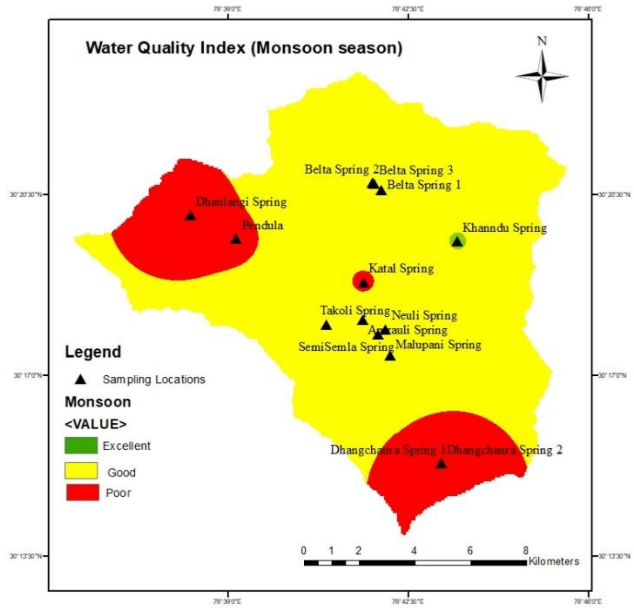


Fig. 15: Spatial distribution maps of water quality index (WQI) in the Takoli Gad Watershed for monsoon season

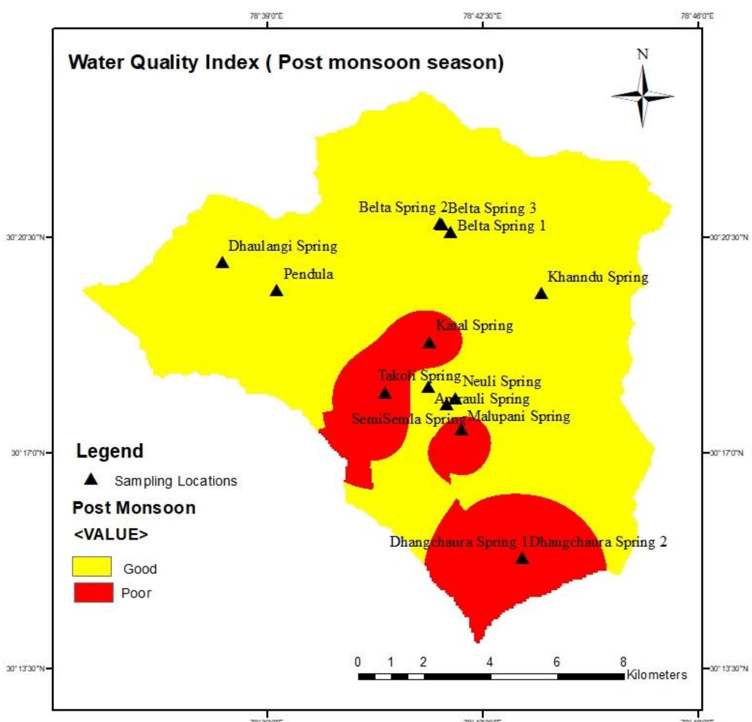


Fig. 16: Spatial distribution maps of water quality index (WQI) in the Takoli Gad Watershed for post monsoon season

For soil samples analysis:

Statistical analysis

Soil quality indicates the ability of soil to function effectively and continuously in the present and in the future. Seasonal variability in the soil functions and conditions are due to factors such as climate pattern, land use, cropping sequences, and farming systems. Sampling for soil quality assessment is crucial to the recommendation of management practices for the overall soil improvement.

After the analysis of soil samples of Takoli Gad watershed of different land use pattern following results were obtained for the pre monsoon, monsoon and post monsoon period for the different parameters (Table16)

Table 16: Descriptive results of soil physicochemical parameters for pre monsoon, monsoon and post monsoon season.

		Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
pH	Pre Monsoon	7.0461	0.59894	0.09982	6.8435	7.2488	4.30	7.70
	Monsoon	7.7283	0.52280	0.08713	7.5514	7.9052	6.70	8.60
	Post Monsoon	7.9375	0.54948	0.09158	7.7516	8.1234	6.71	9.23
Soil Organic Carbon	Pre Monsoon	1.8081	0.78487	0.13081	1.5425	2.0736	0.36	3.45
	Monsoon	2.9314	1.01473	0.16912	2.5881	3.2747	1.04	4.91
	Post Monsoon	2.0736	1.54573	0.25762	1.5506	2.5966	0.02	8.64
EC	Pre Monsoon	169.0636	140.97142	23.49524	121.3657	216.7615	17.04	634.00
	Monsoon	187.8000	105.06187	17.51031	152.2522	223.3478	32.00	550.00
	Post Monsoon	155.1194	97.20905	16.20151	122.2286	188.0103	34.20	439.00
Available Phosphorou s	Pre Monsoon	13.9575	3.82627	0.63771	12.6629	15.2521	8.40	22.56
	Monsoon	5.6778	0.95052	0.15842	5.3562	5.9994	3.90	7.60
	Post Monsoon	5.8306	0.66711	0.11119	5.6048	6.0563	3.80	7.10
Soil Moisture	Pre Monsoon	15.4472	8.14316	1.35719	12.6920	18.2025	2.24	33.42
	Monsoon	16.3289	7.08271	1.18045	13.9324	18.7253	5.77	29.07
	Post Monsoon	8.8786	5.24095	0.87349	7.1053	10.6519	0.35	19.21
Avaialble Potassium	Pre Monsoon	102.4039	20.89934	3.48322	95.3326	109.4752	54.85	149.04
	Monsoon	260.1667	70.46195	11.74366	236.3258	284.0076	110.00	396.00
	Post Monsoon	252.9444	59.17043	9.86174	232.9241	272.9648	148.00	388.00
Bulk Density	Pre Monsoon	1.7725	0.38121	0.06354	1.6435	1.9015	1.02	2.98

	Monsoon	2.0100	2.37125	0.39521	1.2077	2.8123	1.21	15.80
	Post Monsoon	1.2989	0.13201	0.02200	1.2543	1.3436	0.75	1.52
Total Nitrogen	Pre Monsoon	0.3714	0.18954	0.03159	0.3073	0.4355	0.12	0.90
	Monsoon	0.3439	0.18578	0.03096	0.2810	0.4067	0.04	0.86
	Post Monsoon	0.4633	0.21799	0.03633	0.3896	0.5371	0.12	1.10
Available Sulphur	Pre Monsoon	263.2161	119.49366	19.91561	222.7853	303.6469	115.40	564.27
	Monsoon	115.7778	40.33227	6.72205	102.1313	129.4243	35.00	228.00
	Post Monsoon	111.5556	31.44832	5.24139	100.9150	122.1961	40.00	204.00
Available Iron	Pre Monsoon	15.7961	4.77421	0.79570	14.1808	17.4115	3.34	23.83
	Monsoon	9.1944	4.24225	0.70704	7.7591	10.6298	2.85	23.37
	Post Monsoon	8.4219	3.80080	0.63347	7.1359	9.7080	1.25	19.52
Available Zinc	Pre Monsoon	2.6544	0.38071	0.06345	2.5256	2.7833	1.98	3.34
	Monsoon	1.1269	0.81254	0.13542	0.8520	1.4019	0.22	3.59
	Post Monsoon	0.6211	0.15488	0.02581	0.5687	0.6735	0.22	0.84
Available Manganese	Pre Monsoon	11.4114	3.55800	0.59300	10.2075	12.6152	6.20	22.78
	Monsoon	4.8150	1.70607	0.28435	4.2377	5.3923	1.68	9.54
	Post Monsoon	4.2136	2.09134	0.34856	3.5060	4.9212	1.04	9.40
Available Copper	Pre Monsoon	2.6517	0.45028	0.07505	2.4993	2.8040	1.97	3.50
	Monsoon	0.5214	0.32301	0.05383	0.4121	0.6307	0.11	1.46
	Post Monsoon	0.5603	0.30607	0.05101	0.4567	0.6638	0.16	1.42

One-way analysis of variance (ANOVA, $p < 0.05$) is used to find an overall significant difference between all the studied sites and if the significant differences have been employed to identify the differences between the seasons i.e. pre monsoon, monsoon and post monsoon season (Table 17). The relationship strength between variables is determined by using the Pearson's correlation coefficient (Table 19). All the computation of statistics had been performed using the SPSS software v. 26 (2019) and Microsoft Excel (2016) for windows.

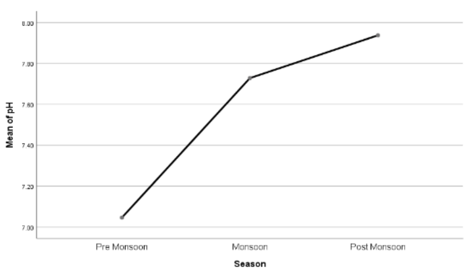
Table 17: ANOVA for different season i.e. pre monsoon, monsoon and post monsoon

		Sum of Squares	Mean Square	F	Sig.
pH	Between Groups	15.645	7.823	25.126	0.000
	Within Groups	32.689	0.311		

	Total	48.334			
Soil Organic Carbon	Between Groups	24.819	12.409	9.226	0.000
	Within Groups	141.225	1.345		
	Total	166.044			
EC	Between Groups	19362.129	9681.065	0.720	0.489
	Within Groups	1412618.775	13453.512		
	Total	1431980.904			
Available Phosphorous	Between Groups	1615.492	807.746	151.558	0.000
	Within Groups	559.609	5.330		
	Total	2175.102			
Soil Moisture	Between Groups	1193.168	596.584	12.434	0.000
	Within Groups	5038.015	47.981		
	Total	6231.182			
Available Potassium	Between Groups	571244.561	285622.280	96.247	0.000
	Within Groups	311598.279	2967.603		
	Total	882842.840			
Bulk Density	Between Groups	9.435	4.718	2.446	0.092
	Within Groups	202.495	1.929		
	Total	211.930			
Total Nitrogen	Between Groups	0.282	0.141	3.582	0.031
	Within Groups	4.129	0.039		
	Total	4.410			
Available Sulphur	Between Groups	537081.761	268540.880	47.686	0.000
	Within Groups	591304.792	5631.474		
	Total	1128386.552			
Available Iron	Between Groups	1182.685	591.343	32.117	0.000
	Within Groups	1933.255	18.412		
	Total	3115.940			
Available Zinc	Between Groups	80.683	40.341	145.962	0.000

	Within Groups	29.020	0.276		
	Total	109.703			
Available Manganese	Between Groups	1148.184	574.092	86.357	0.000
	Within Groups	698.032	6.648		
	Total	1846.216			
Available Copper	Between Groups	106.962	53.481	400.346	0.000
	Within Groups	14.027	0.134		
	Total	120.989			

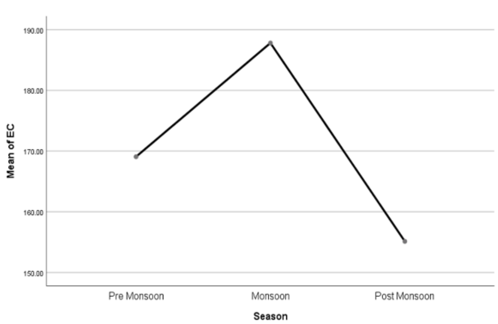
Mean Plot of pH



pH of the soil of Takoli Gad watershed found to be alkaline in nature. Highest value of pH is observed in post monsoon season (Fig. 18)

Figure 17: Mean plot pH

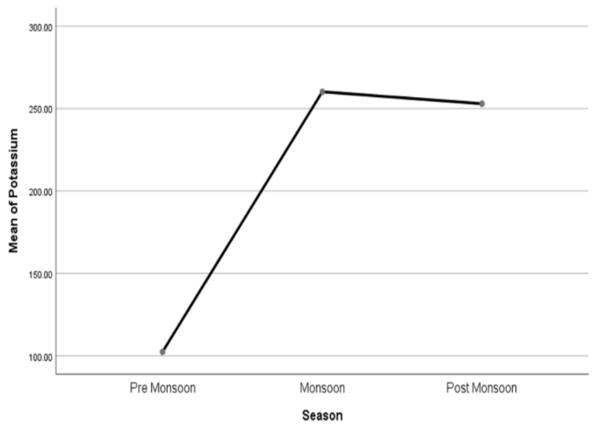
Mean Plot of Electrical conductivity



Highest value of electrical conductivity is observed in Monsoon season followed by pre monsoon and least value in post monsoon season (Fig. 19).

Figure 18: Mean plot of Electrical conductivity

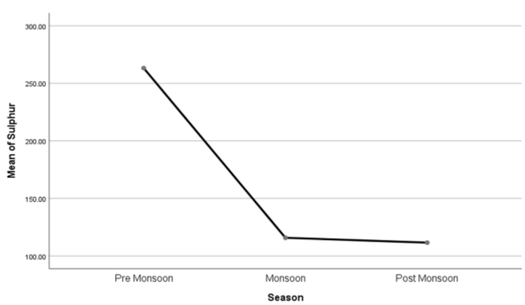
Mean plot of Available Potaasium



Highest value for the available potassium is observed in the monsoon season followed by post monsoon season and lowest value is observed in pre monsoon season (Fig. 20).

Figure 19: Mean plot of available potassium

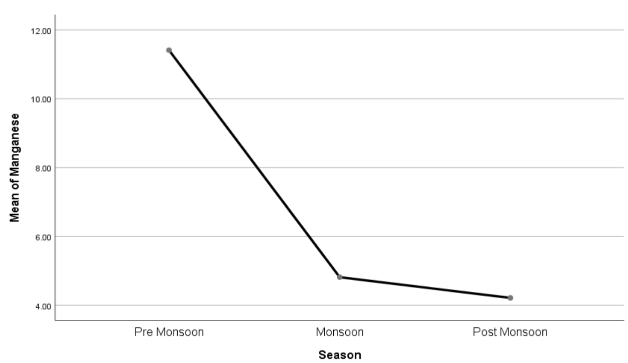
Mean plot of Available Sulphur



Highest value for available sulphur was observed in pre monsoon season followed by monsoon and post monsoon season (Fig. 21)

Figure 20: Mean plot of available sulphur

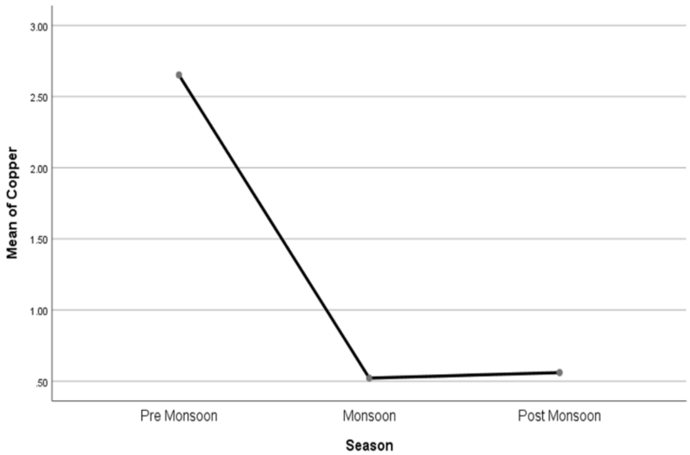
Mean plot for Avaialable Manganese



Highest value for available Manganese was observed in pre monsoon season followed by monsoon and post monsoon season (Fig. 22).

Figure 21: Mean plot of Available Manganese

Mean plot for Available Copper



Highest value for available Manganese was observed in pre monsoon season followed by post monsoon and monsoon season (Fig. 23).

Figure 22: Mean plot of available copper

Micronutrients of soil:

Micronutrients may be found in small amounts in the soil but they play a huge role in plant growth and development. In fact, most micronutrients in the soil are involved in critical enzymatic reactions such as photosynthesis and respiration. Range of micronutrients in soil of Tehri Garhwal (Shukla et al., 2015) shown in table 18. All essential micronutrients are found within the range of critical levels of Takoli Gad watershed.

Table 18: Range of micronutrients in soil of Tehri Garhwal

Micronutrients	Range of critical level (mg/kg)
Cu (DPTA)	0.38-14.96
Mn (DPTA)	1.99-55.86
Fe (DPTA)	3.74-79.32
Zn (DPTA)	0.21-18.14

Pearson Correlation Matrix:

The correlation netween soil indicators are listed in table 19.

Table 19: Correlation between different indicators of soil

	pH	SOC	EC	AP	SM	AK	BD	TN	AS	Fe	Zn	Mn	Cu
pH	1												
SOC	0.240*	1											
EC	0.057**	0.240*	1										
AP	-.479**	0.273**	0.045	1									
SM	0.004	0.299**	0.294**	0.192*	1								
AK	.381**	0.131	-0.113	**-0.708****	-0.214*	1							
BD	-0.021**	-0.035	-0.060	-0.027	-0.025	-0.067	1						
TN	0.046	0.184	0.057	-0.016	-0.001	-0.025	-0.084	1					
AS	-.458**	-0.197	0.076	**0.585****	0.127	**-0.531****	-0.022	-0.026	1				
Fe	-.281**	-0.138	-0.049	**0.551****	0.203*	-0.474**	0.040	0.016	0.372**	1			
Zn	**-0.519****	0.226*	-0.008	**0.731****	0.268**	**-0.652****	0.135	-0.088	**0.512****	**0.599****	1		
Mn	**-0.524****	-0.211*	0.048	**0.622****	0.027	**-0.659****	0.075	-0.133	**0.612****	0.401**	**0.610****	1	
Cu	**-0.566****	-0.273*	-0.009	**0.814****	0.189	-0.749**	0.117	-0.059	**0.621****	**0.642****	**0.803****	**0.704****	1

*. Correlation is significant at the 0.05 level (2 tailed)

**. Correlation is significant at the 0.01 level (2 tailed)

Soil Quality Analysis using Principal Component Analysis:

SPSS software was used to conduct the Principal Component Analysis (PCA). PCA was used to reduce the dataset into new variables, which are called principal components (PCs) as well as to avoid multicollinearity between the original variables (Fatteh et al., 2021). These PCs explain most of the variation present in the original variables (Peraza et al., 2017). The results of PCA are summarized in figure 23 and 24. The first three principal Components have eigenvalues greater than 1. The result shows that first three PCs explain 61.32% of variance. According to the factor loading, the first PC, which explains 40.275% of the total variance, has negative correlation with Zinc (Zn), Mn (Manganese) and Cu (Copper).

Total Variance Explained			
	Initial Eigenvalues		
Component	Total	% of Variance	Cumulative %
1 pH	5.236	40.275	40.275
2 Soil Organic Carbon	1.653	12.714	52.989
3 EC	1.083	8.331	61.319
4 Available Phosphorous	0.992	7.632	68.952
5 Soil Moisture	0.877	6.745	75.697
6 Available Potassium	0.686	5.276	80.973
7 Bulk Density	0.591	4.545	85.518
8 Total Nitrogen	0.513	3.949	89.467
9 Available Sulphur	0.469	3.607	93.074
10 Available Iron	0.303	2.334	95.408
11 Available Zinc	0.258	1.984	97.393
12 Available Manganese	0.220	1.693	99.086
13 Available Copper	0.119	0.914	100.000

Fig 23: Percent of Variance shown by components of soil

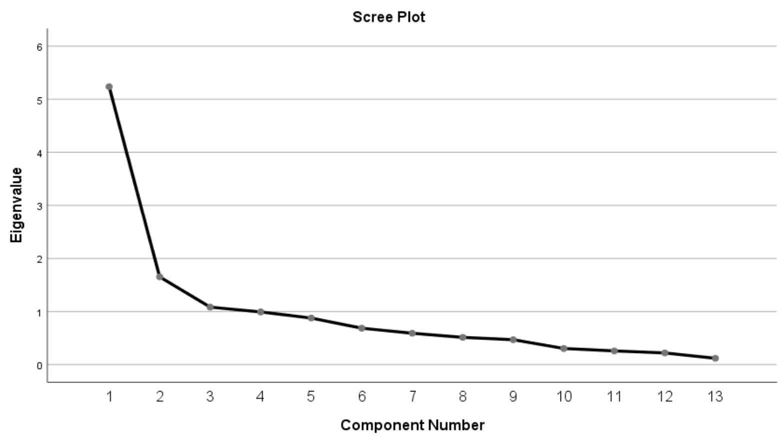


Fig24: Scree plot for the different components considered for the PXCA with eigenvalues

<u>Objective 4: Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability</u>.

Identification of variables for women: Following parameters are identified through literature review and field survey in the study area i.e. women respondents on the following aspects: Women role in forest conservation activities, role in soil conservation, role in decision making, management of existing natural water sources, women involvement in water collection, involvement of women in livelihood, involvement of women in watershed programs, drudgery faced by women in collection of water, fodder and fuel (Time taken, frequency of activity and difficulty perceived)

Demography: Takoli Gad watershed consists of **67** villages. Total population of watershed is **15771** (according to 2011 census). Total numbers of households are **3572**. Number of males are **7332** and number of females are **8721**. The population density of the watershed is **135.16** person per square km.

Literacy pattern of the watershed is **10451** whereas number of illiterates present in the watershed are 5411**.**

Socio economy: The main occupation of villagers in Tehri district is agriculture. The agricultural activities are confined to gentle sloped, river terraces and intermountain valleys. Rice, wheat, maize, pulses, millets, garlic, ginger, and seasonal vegetables are the major crops grown in the watershed. Other sources of employment are wage labor, agriculture labor, government jobs, business occupations.

Land use pattern: Watershed is divided into different land use categories i.e. agricultural land, barren land, non-agricultural land, forest land (Table 20). Villagers depend on the forest for the fuel wood and fodder collection. Major fuel wood species found in the forest are *Alnus nepalensis, Quercus floribunda, Pinus roxburghi, Rhododendron arboretum, Rhus purviflora, Toona ciliate*.

Table 20: Details of various land use categories of Takoli Gad Watershed

Land use category	Area in hectares
Agricultural land	**2825.37 ha**
Irrigated land Non irrigated land	310.66 ha 2514.71 ha
Barren land	**2700. 29 ha**
Non-agricultural land	**388.62 ha**
Water bodies Settlement Others	37.46 ha 60.59 ha 290.57 ha
Forest land	**7228.9 ha**

This research examines the roles played by women for conserving and managing the watershed sustainability. The Takoli gad watershed consists of total six vikas khand areas which comprises of total 67 villages (Fig. 25). The study takes a gender and social inclusion perspective with aim to identify the gender roles in conservation of natural resources sustainably. The project adopted a mixed methods approach to understand the gender and social norms existing in the study region. A socio economic survey, PRA and focused group interviews were conducted. Analysis of gender aspects particularly women’s role in watershed management is carried out. The survey involved 400 respondents were randomly chosen and interviewed from different vikas khand area. A brief profile of the vikas khand areas is given in the table 21. Stratified random sampling method was adopted in drawing the sample from the study area. Data was generated from 400 respondent’s individuals from the interviews. About 30-40 men and women were interacted through focus group discussions in each vikas khand area of the Takoli Gad watershed.

Among 400 respondents, 250 were female and rest of them were male and a majority of respondents belonged to the age group of 20-60 years. 15 percent respondents were illiterate. Most of them were just having education level only up to higher secondary level.

Table 21: Characteristics of the six different Vikas khand areas of the Takoli Gad watershed

Vikas Khand Areas	Akri	Bajrula	Kadakot	Badiyar Gad	Maletha	Dagar
Total number of Villages	15	7	19	1	8	67
Total number of households	411	642	863	49	326	1281
Male (%)	10.71	17.3	24.09	1.25	8.93	37.72
Female (%)	10.72	17.31	24.47	1.07	8.09	38.34
Literate (%)	8.99	18.21	23.31	1.19	9.23	39.07
Illiterate (%)	9.98	16.14	27.05	1.14	8.25	37.44
SC (%)	4.98	24.74	27.1	0.08	12.8	30.3
ST (%)	82.92	3.67	0	0	7.31	6.1

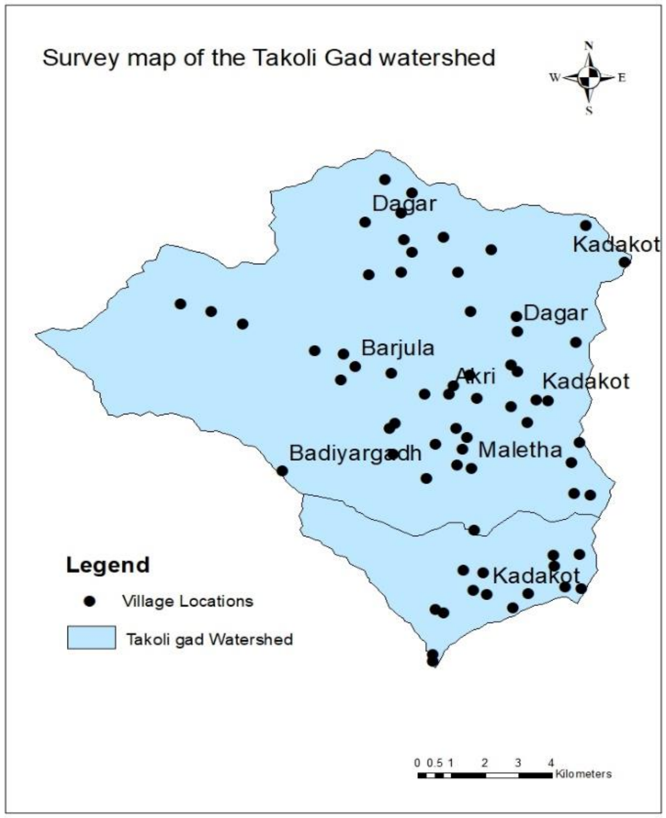


Fig. 25: Survey villages map of Takoli Gad watershed

Household headship and decision making: To understand the type of households, the headship in the households were listed out. In all the locations majority of the households had both male and female adults who are involved in everyday running of households and agricultural activities. Overall, 65 % of the male members were solely responsible for all the decision made for their households. The jointness in decision making that was reported 33% which means that both men and women participated in decision making process equally but the minimum was that they were informed about the decisions.

Source of income: the survey revealed that there was diversification on livelihoods and this a diversification of income from different sources (Fig. 26). Farming and earning crops (42%), livestock (8%), wages (30%), pension (2%), government jobs (9%), private jobs (6%) and business (3%). Farming is the major source of income for livelihood in the Takoli Gad watershed.

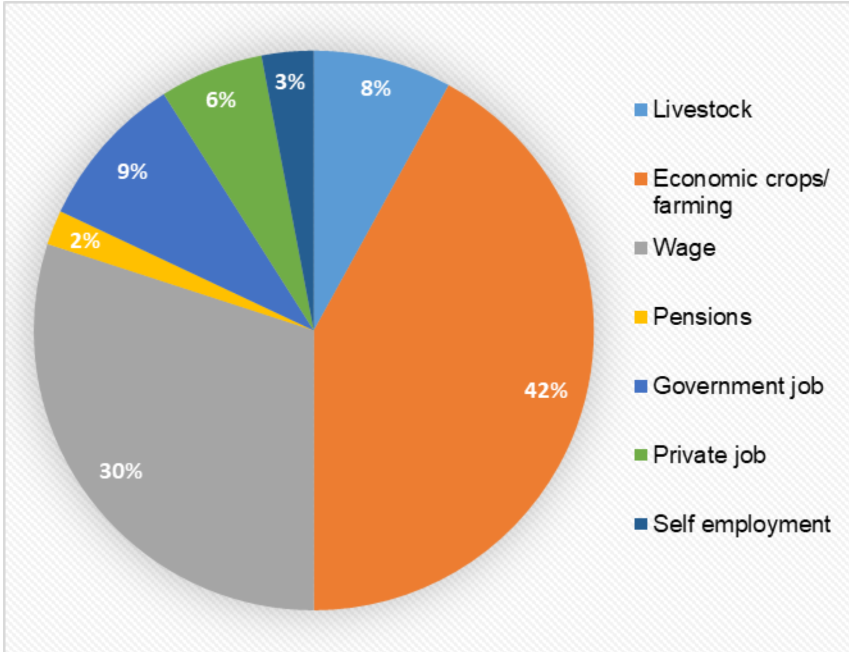


Fig 26: Different source of income of local people in Takoli Gad watershed

Women contribution in various activities in the watershed: The natural resources which are directly concerned with rural women are drinking water, fuel wood and fodder. The needs of these women with specific reference to available natural resources have to be identified. Independent participation of women is higher in the households and homestead garden activities followed by livestock management (Sidh, & Basu, 2011) (Fig 27). Joint participation of women with men was lesser then the independent participation of women in all activities area. Women spend 40.2 % of their time per season including major activities transplanting, harvesting and weeding. All other activities such as shed-cleaning, milking, harvest and transport of grass for livestock are performed exclusively by women. Women contributes (fig 28) about 88% in animal care activities, cooking activities contribution is 95 %, water collection contributes about 90 %, contribution for fuel wood and fodder collection (97%), agricultural activities (88 %).

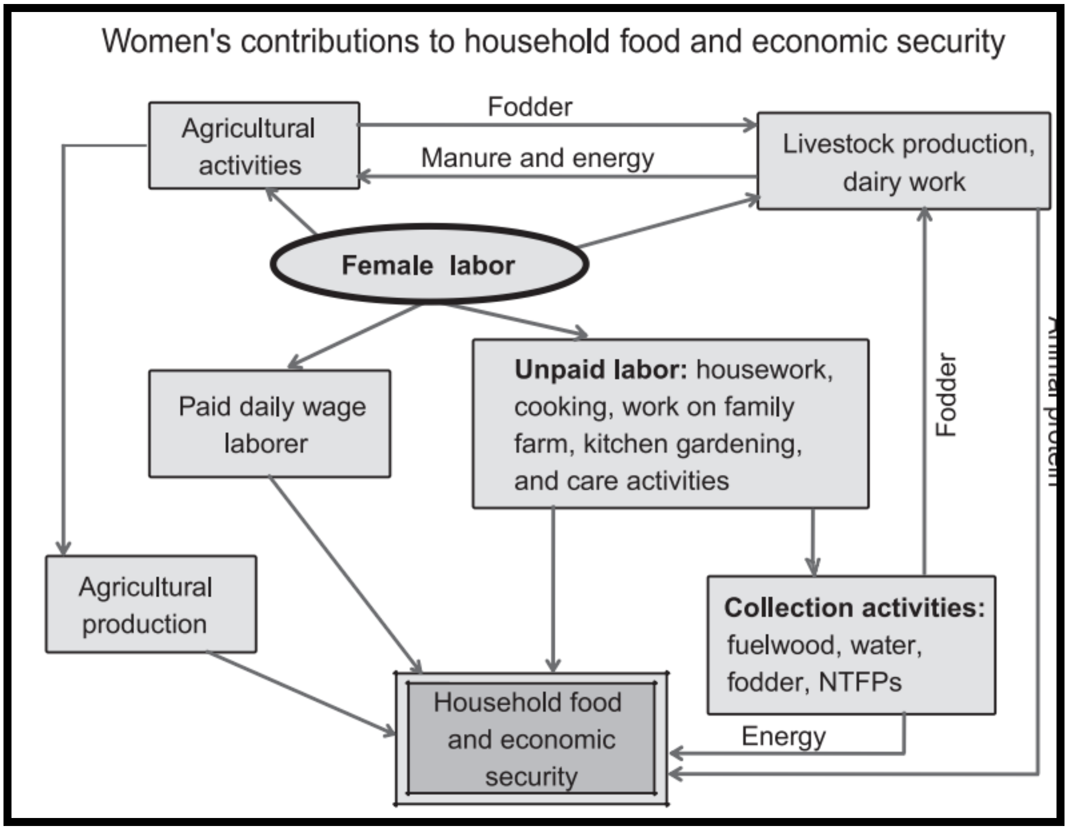


Fig 28: Women's contribution to household food and economic security (Sidh, & Basu, 2011)

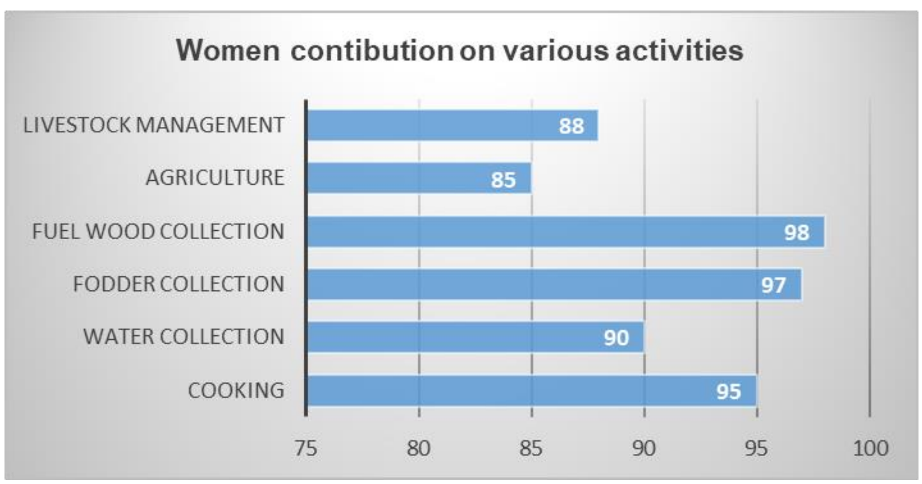


Fig 29: Women contribution in various activities in the watershed

Major challenges faced by the local people in the watershed:

- Waters supply problem
- Participants cited considerable loss of agricultural fields over the time and face lots of challenges in growing crops due to destruction of crops by monkeys and wild pigs in the area.

- Education: Lack of quality education and non-availability of teachers in schools.
- Health: Lack of medical facilities, lack of hospitals only aurveydic dispensaries are found.
- Awareness: Men and women are not aware of and knowledgeable about national policies, acts, regulations and goals that prioritize equitable access to resources, participation and benefits between men and women.

Key Results

- The morphometric analysis of Takoli Gad watershed shows dendritic drainage pattern, which develops over the soft sedimentary rocks and indicating that topographical features in hilly regions are dipping, folded and jointed (Biswas, 2016). The low bifurcation ratio of each sub watershed specifies that structural disturbances are minimal (Javed et al. 2011). Variation in stream length ratio indicates a late youth stage of geomorphic development. Low Drainage density of the study area which indicates highly permeable subsoil, vegetative cover and very coarse drainage. The relief ratio of the watershed highlights the mountainous topography, showing a higher energy basin with intense erosion and high sediment load which signifying high erosivity. The watershed has a high ruggedness number indicating a high risk of soil erosion.
- The presence of excellent to good potential zone in the Takoli Gad watershed due to presence of high rainfall, lower slope degree, lower elevation, low drainage density, agriculture and forest cover in land use land cover and phyllite as dominant geology in these regions. The moderate resource potential zones occur generally in the watershed with an areas of high drainage density. In contrast to the poor and very poor potential zones are characterized by the lithology of shale, limestone and quartzite, higher slope degree, low rainfall and high drainage density. Therefore, low chances of infiltration and more rainfall is expected to flow in the form of runoff. The resource potential areas have been categorized based on joint effect of various parameters. Thus finding the resource potential zones helps in accurate zones for exploration for agricultural and sustainable utilization of natural resources and land management.
- Water quality analysis is important for present conditions can be useful in the same ecological conditions at the future review to accessibility of safe drinking water. Seasonal changes are usually defined by the precipitation and temperature at various times over the year. The whole monitoring period was divided into three seasons, namely, pre monsoon, monsoon and post monsoon.
- In order to study the relationships among multiple variables through Pearson's correlation matrix. The strength of the association between two or more variables is explained with

weak ($r<0.500$) and strong ($r \geq 0.500$) correlations. EC was strong and positively correlated with TDS (r = 9.17), TH (r = 7.14), Ca^{2+}(r = 0.755) and Na^{+} (r = 0.764) found to be significant at $p<0.01$ level. Similarly, TH shows strong and positive correlation with Ca^{2+} (r = 0.944) and Mg^{2+}(r = 0.899), significant at $p<0.01$ which supports the occurrence of temporary hardness.

- From WQI, spring water can be ordered into five classes based on WQI values. According to the categorization out of total samples analyzed 28% spring samples comes under excellent water class, 72% samples has a place with good water class for Pre monsoon season, while 7 % of samples belongs to excellent water category where as 57 % samples were found of good water category and 36 % samples were found under poor water category for monsoon season and 64 % samples belongs to good water category and 36 % samples were found under poor water category for post monsoon season.
- One-way analysis of variance (ANOVA, $p < 0.05$) is used to find an overall significant difference between all the studied sites and if the significant differences have been employed to identify the differences between the seasons i.e. pre monsoon, monsoon and post monsoon season.
- ANOVA, ($p < 0.05$) seems to be significant for all the physicochemical parameters except electrical conductivity and bulk density (P value > 0.05). These parameter does not have any significant variations for the pre monsoon, monsoon and post monsoon season.
- Principal Component Analysis (PCA) was used to reduce the dataset into new variables, which are called principal components (PCs) as well as to avoid multicollinearity between the original variables. The first three principal Components have eigenvalues greater than 1. The result shows that first three PCs explain 61.32% of variance. According to the factor loading, the first PC, which explains 40.275% of the total variance, has negative correlation with Zinc (Zn), Mn (Manganese) and Cu (Copper).
- A socio-economic survey, PRA and focused group interviews were conducted. Analysis of gender aspects particularly women's role in watershed management is carried out. The survey involved 400 respondents were randomly chosen and interviewed from different vikas khand area which comprises of total 67 villages.
- Based on the field surveys and PRA studies, some parameters were identified which shows the contribution of women in various activities performed in the watershed. Various challenges faced by the local people in the watershed i.e. waters supply problem, wildlife problems, lack of quality education (non-availability of teachers in schools), lack of medical facilities, lack of hospitals (only aurveydic dispensaries) are present, lack of awareness about the policies, different schemes and programmes of the watershed management.

- The natural resources which are directly concerned with rural women are water for drinking and domestic purposes, fuel wood and fodder. Independent participation of women is higher in the households and homestead garden activities followed by livestock management. Joint participation of women with men was lesser then the independent participation of women in all activities area.
- Overall, 65 % of the male members were solely responsible for all the decision made for their households. The jointness in decision making that was reported 33% which means that both men and women participated in decision making process equally but the minimum was that they were informed about the decisions.
- The role of women in many poor households as the gatherers of fodder and fuel, it often falls to them to contribute this labor on behalf of their households. Protection of a degraded area may transfer harvesting pressure to another area and this increase women's (and children's) drudgery if they have to travel a greater distance to collect their daily requirements of fuel and fodder. The increase in the workload of women, needs to be recognized as they walk further for fuel and fodder or even water while nearby resources are replenished through land development works.
- Women involved in watershed committees and other village institutions are often not given a chance to voice their opinions and access to information to participate in informed decision-making.
- Women's involvement in the planning and implementation of soil and water conservation and in managing newly created resources in the watershed is limited.
- Women need to be involved in planning and implementation of plans not only at village level but also at higher level which strengthens the participation of women in watershed programmme.
- The active participation of women will promote benefits such as
    - access to a reliable source of safe drinking water within a reasonable distance, and improvements in health and hygiene. It is found that often the irrigation and watershed activities that enhance water access for agriculture ignore women's water needs for household purposes, livestock etc.
    - Access to a steady flow of income to ensure food, fuel and financial security.
    - A secure future for their children through education.
    - Participation in household decision-making and community affairs.

3.3 Conclusion of the study undertaken

- The morphometric parameters helped in understanding various terrain parameters such as nature of bedrock, infiltration capacity, surface runoff, etc. The present study illustrated the procedure of delineating and quantifying morphometric parameters in Takoli Gad watershed with the help of digital elevation model using ArcGIS software. The morphometric study helps in understanding the watershed characteristics.
- Takoli gad watershed has highest fifth order stream and coarse texture. The watershed has experienced structural disturbance and is oval in shape. The watershed has steep slope which led to more runoff. Modest soil erosion is observed in the watershed hence conservation method can be proposed for the conservation of the natural resources available in the study region. The primary aim of this analysis is to investigate the potential application of AHP, GIS and RS approaches to map resource potential zones. Areas with low drainage density, high rainfall, lower slope and elevation also have a good to excellent resource potential zones. Due to hydrogeological conditions of the subsurface, hard-rock terrain in the northern part of the study area resulted in a low groundwater potential. The resource potential map accuracy has been confirmed using field data indicates that this approach of prediction is effective and reliable.
- Water quality assessment of the springs is essential because rural people is entirely dependent on the springs for their basic essential needs. Samples of spring water were analyzed for pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, nitrate, calcium, magnesium, sodium, potassium, and total hardness. The outcomes were validated by comparing with WHO and BIS criteria for drinking water quality. Water chemistry of the identified perennial springs in Takoli gad watershed shows that Mg^{2+} and HCO_3^{-} are predominant ions among cations and anions as well as Ca (Mg) HCO_3 type, bicarbonate type, and magnesium type as dominant water (Taloor et al., 2020).
- The descriptive analysis of soil quality indicators suggests that the Takoli Gad watershed soils are suitable for cultivation. Pearson correlation and Principal Component Analysis reflected relations between some of the indicators analyzed, such as exchangeable cations and soluble cations and anions. Based on the above mention statistical analysis, electrical conductivity, bulk density, pH, soil organic matter, available phosphorous, available potassium and essential micronutrients were identified as the more representative indicators of the soil of different land use pattern of Takoli Gad watershed.

- Based on the field visits, surveys and PRA activities many issues were highlighted like lack of water supply system to various villages, poor health services, loss of agricultural yields due to destruction caused by wild animals, forest fire which leads to loss of fodder and fuel wood. Local people men and women both are unaware about the watershed policies and guidelines. The main source of occupation is agriculture and labor wages which they got under MNREGA scheme.
- There is need of training, skill development activities and workshops to be conducted in the watershed to enhance the sustainable livelihood status of the local people mainly included women that enhance water access for agriculture, water needs for household purposes, livestock etc., access to a steady flow of income to ensure food, fuel and financial security and participation in household decision-making and community affairs.
- The inclusion of women in decision-making processes is a pre-requisite to sustainable development in rural environments, especially for ensuring water security. Watershed intervention projects require gender transformative approaches across all social levels, from the household and community.

OVERALL ACHIEVEMENTS

4.1 Achievements on Objectives

- **Characterization the watershed on the basis of available resources**
  - The basic resources estimation of the study area provides the base line data of the watershed. The present study summarized the importance and utility of integrated and holistic approach using remote sensing and GIS techniques in geo-morphometry, including geophysical and land use land cover based analysis to delineate the morphometric parameters and characterization of watershed. The results of the analysis indicated that the morphometric features could be used to characterize a micro-watershed and determines its susceptibility to erosion as well as comprehend the basin hydrological behavior. The risk potential of the watershed is specially indicated by geo-morphometry integrated with land use categories, soil type and geology. The findings will be useful for erosion controls and watersheds management strategies in a sustainable manner.
  - Elevation, slope, geology, soil, rainfall, land use land cover, and drainage density are the seven parameters those are thoroughly analyzed to evaluate the resource potential zones of the study area. Thematic layer of the above mentioned parameters is prepared. The relative influence value and AHP weight calculated for resource potential zones.

- A composite map of the Resource Potential Zones is developed for Takoli Gad watershed. The resource potential zones categorize into five different zones i.e. the excellent (1.59 %), good (25.61%), moderate (45.21 %), poor (26.41 %), and very poor (1.18 %) zones watershed.

- **Assessment of physiochemical parameters of soil and water in the watershed**
    - The water physicochemical parameters measures show seasonal variations. Water quality Index for the spring water was developed for the pre monsoon, monsoon and post monsoon season.
    - The outcomes were validated by comparing with WHO (2011) and BIS (2012) criteria for drinking water quality. As per the BIS and WHO standard value of drinking water, spring water samples are in the acceptable cap.
    - Analysis of soil samples of Takoli Gad watershed for different land use pattern results were obtained for the pre monsoon, monsoon and post monsoon period for various physicochemical parameters. The values are validated by comparing with soil health card, ICAR.

- **Watershed integrity index of the studied area**
    - Watershed integrity index is yet to be calculated.
    - Outcome of the research work will be the part of the PhD thesis. This objective will be compiled in the PhD thesis work.

- **Suggestion for comprehensive plan and assessment of roles played by women for conserving and managing the watershed sustainability**
    - Determine the role played by rural women in managing the natural resources.
    - Gender equality concept does not exist in the male dominated patriarchal system that is still going strong. Low literacy among women, exclusion through non communication with outsiders and with men, restricted mobility of women.
    - Women face greater constraints to production through lack of access to assets, resources and services.
    - Men and women are not aware of and knowledgeable about national policies, acts, regulations and goals that prioritize equitable access to resources, participation and benefits between men and women.

- Women involved in watershed committees and other village institutions are often not given a chance to voice their opinions and access to information to participate in informed decision-making.
- Women's involvement in the planning and implementation of soil and water conservation and in managing newly created resources in the watershed is limited.
- Women need to be involved in planning and implementation of plans not only at village level but also at higher level which strengthens the participation of women in watershed programmme.

4.2 Establishing New Database/Appending new data over the Baseline Data

- Morphometric characterization of the Takoli gad watershed, various thematic layers of the selected parameters and identification of the resource potential zones were computed using different morphometric and hydrology tools, and ArcGIS tools.
- Assessment of water quality and various physicochemical parameters of the selected perennial springs in the Takoli Gad watershed were analyzed for different seasons i.e., pre-monsoon, monsoon and post monsoon period and water quality index was calculated for seasonal variation.
- Assessment of soil quality of different land use pattern i.e., forest, agricultural, settlement and waste and other physicochemical parameters in the Takoli Gad watershed were analyzed for different seasons i.e., pre-monsoon, monsoon and post monsoon period.

4.3 Generating Model Predictions for different variables: Not Applicable

4.4 Technological Intervention: Not Applicable

4.5 On-field Demonstration and value-addition of products: Not Applicable

4.6 Developing Green skills in IHR: Not Applicable

4.7 Addressing Cross-cutting Issues

- Integrated watershed development program has encountered many threats.
- Lack of baseline data for monitoring and comparison of the current conditions of the watershed leads to natural exploitation and ineffective management which lead to the depletion of resources in both quality and quantity.
- Lack of equity sharing of benefits to small land holders, landless, labour and women
- Cultural and social constraints are limiting factors regarding rural women's involvement in watershed management.
- Lack of awareness among the local people about the various government schemes, policies and livelihood programmes.

- Limited access to the fresh water, local people mainly depend on the spring water to fulfill their drinking and domestic needs. The primary occupation of the local people in the Takoli Gad watershed is agriculture. Participants cited considerable loss of agricultural fields over the time and face lots of challenges in growing crops due to destruction of crops by monkeys and wild pigs in the area. Lack of quality education and non-availability of teachers in schools. Lack of medical facilities, lack of hospitals only aurveydic dispensaries are found.
- The study facilitates the identification, prioritization and execution of work through participatory approach involving all section of people.

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Field survey, Focus group discussion and PRA photographs


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5 IMPACTS OF FELLOWSHIP IN IHR

5.1 Socio-Economic Development

- Increasing the awareness regarding the role of women in watershed and disaster management opportunities and challenges including all section of people such as women and children who are most vulnerable in the community.
- The inclusion of capacity building programmes such as SHGs and NRLM (National Rural Livelihood Mission) under MNREGA scheme that promote better livelihood options specifically for the social development of the rural women.

5.2 Scientific Management of Natural resources in IHR

- In IHR, the application of multi-criteria decision analysis and advanced geospatial techniques (remote sensing, Geographical Information System (GIS), and GPS) approach provide a comprehensive opportunity for planning and management of natural resource and disaster management on a large scale.
- Watersheds therefore, an integral unit for development and environmental planning purposes. Watershed-based planning for natural resource management has recently received a lot of attention. Also, it is a social and biological entity having similar land, climate and water resource conditions.

5.3 Conservation of Biodiversity

- Himalayan ecosystem is vulnerable and susceptible to the consequences of climate change. Land use change, increased incidents of forest fires, climate change and increasing anthropogenic activities all pose threat to Himalayan biodiversity.
- Effective watershed management has been identified as an appropriate spatial unit for management and it is also increasingly recognized as the key scale for resource governance. Watershed management uses community-based approaches. In watershed management, there is a high level of community participation, with women having a significant impact. Gender relations need to be considered in all aspects of watershed management and women should be able to actively bring their contribution as key stakeholders.
- Diagnostic studies and mapping exercises can be carried out using participatory appraisal, mapping and planning tools to evaluate the situation, analyze upstream–downstream linkages, establish watershed management committees, prepare watershed management plans, and implement improved practices and technologies.

5.4 Protection of Environment

- Climate change poses a serious threat on the Indian Himalayan Region. The majority of the population is directly or indirectly depend on the ecosystem services provided by the Himalayan region ultimately affecting local people of the community. It has large impact on land use pattern such as water, forest and agricultural practices.
- Himalayan communities mainly depend on the agriculture and forest for their livelihood while both are affected largely by impact of climate change. Incidences of flash flood, soil erosion, landslide, erratic and unpredictable weather conditions, changing pattern of rainfall, forest fire are enhanced by the climate change.
- River basins studies should be prioritized in order to identify vulnerable areas and develop adaptive measures in response to landslides, forest fire, floods and droughts.
- Promote awareness, knowledge, involvement and participation of the local communities and technological infrastructure
- Women play an essential role in natural resources management and in other productive activities at the household and community levels. This enables them to contribute to livelihood strategies that are adapted to changing environmental realities. Their extensive knowledge and expertise, which can also be implemented in climate change mitigation, disaster reduction and adaptation strategies, make them effective actors and change agents (Wanjiru, 2012).
- More participation of women, is also expected to enhance the effectiveness and sustainability of climate change projects and policies. Women, for instance, are typically very effective at mobilizing communities in the case of disasters and disaster risk management and reduction and have a clear understanding of what strategies are required at the local level (Wanjiru, 2012).

5.5 Developing Mountain Infrastructure: Not Applicable

5.6 Strengthening Networking in IHR

- Skill Development: The lack of skilled manpower is a significant challenge in the region. Providing vocational training and educational opportunities to the local population can help in creating a skilled workforce that can contribute to the region’s development.
- During the frequent field visits for collection of primary and secondary data in the study area interaction have been made with various stakeholders including local people of the communities, district and state administrators, scientist and researchers.

- Need of joint efforts for better collaboration, bottom to up approach for successfully implementation of plans and policies in the region with the equal participation and contribution of the local people with the different stakeholders like government department, NGOs in the region.
- During the household surveys, focused group discussions, PRA activities strong links were formed with the local communities and representatives from the study area. The awareness program conducted during the study also helped local people to speak up their problems and to have sense of various schemes run by the government for disaster and watershed management. Interacting with local communities helped in establishing the dialogue about the ground level problems faced by the women of the study area.
- The methodology followed and outcomes of the present study can be replicated to other areas of the IHR having similar issues.
- District and block level identification of the vulnerable areas help for targeting prioritization efforts, emergency response measures, channelizing funds, and raising environmental concern and policy interventions at district level for mitigating disaster vulnerability and watershed management in the country.
- The study has led to the creation of local level risk-related data and knowledge base which will be helpful in generational exchanges and outreach of timely user-friendly scientific, information on watershed and disaster risk management.

6 EXIT STRATEGY AND SUSTAINABILITY

6.1 How effectively the fellowship findings could be utilized for the sustainable development of IHR

The major fellowship findings include the development of individual natural hazards susceptibility maps of the hazard prone districts of the Indian Himalayan Region i.e. Tehri Garhwal, Rudraprayag and Chamoli. These districts witnessed number of natural disasters such as landslides, forest fires and flashfloods in the recent past. All the GIS layers and individual hazard susceptibility maps of the study region will provide indispensable information about the present and future natural hazards to the people, engineers and planners in an easy to understand format so that the appropriate mitigation measures could be formulated. The individual hazard susceptibility maps of the study district could be utilized as important tool for sustainable development planning in the Indian Himalayan region in number of ways such as:

Risk reduction and disaster management: Hazard susceptibility mapping identifies the areas that are more prone to natural hazards. This information can be used to develop risk reduction and disaster management strategies that can help minimize the impact of disasters on people and their property.

Land-use Planning: Natural hazard susceptibility mapping can guide land use planning decisions in the IHR. For example, areas identified as being at high risk of landslides or floods can be zoned as protected areas or restricted for certain land uses to prevent or mitigate disaster risk.

Infrastructural development: outcome of the susceptibility maps could be utilized to inform decisions about infrastructural development. It can help identify the areas where infrastructure such as roads and buildings should be avoided and where protective measures such as retaining walls or drainage system should be put in place.

Capacity building: All susceptibility maps will help the locals in the study area to understand the current scenario of disaster risk so that they can self-prepare them to minimize the loss due to such natural calamities.

Identified women's vulnerability in natural disasters in the study area provide valuable insights into the gendered impacts of disasters and inform policies and programs to promote sustainable development in the region. Here are some ways in which the findings of present study can lead to sustainable development:

Gender-sensitive disaster risk reduction: Identified women's vulnerability factors in the current study provide insights into the gendered impacts of disasters, such as the disproportionate impact on women's livelihoods, health, and safety. This information can inform disaster risk reduction policies and programs that are sensitive to gender issues, such as providing safe shelters for women and ensuring access to reproductive health services.

Women's empowerment: Women's vulnerability in natural disasters is often linked to their lower social and economic status in society. Addressing these structural inequalities help empower women and build their resilience to future disasters. For example, providing women with access to education, healthcare, and livelihood opportunities can improve their overall well-being and help them cope with the impacts of disasters.

Sustainable livelihoods: Natural disasters can have a significant impact on women's livelihoods, particularly in rural areas where women often rely on agriculture and other natural resources for their livelihoods. Disaster management policies and programs can help promote sustainable livelihoods for women by supporting sustainable agricultural practices, promoting renewable energy sources, and creating opportunities for women to engage in income-generating activities that are resilient to natural disasters.

Community resilience: Women play a critical role in building community resilience to natural disasters. Present study provides valuable insights into the gendered dynamics of community resilience and informs policies and programs that promote women's participation in disaster preparedness, response, and recovery efforts.

Assessment of the basic resources in the watershed gives an estimate of the resource status of the study area. The resultant information such as water quantity and quality in the study area could be used to develop sustainable water management strategies such as rainwater harvesting, water conservation and water reuse. Results of the soil quality can be used to develop sustainable agricultural practices such as crop rotation, conservation tillage, and integrated pest management. Watershed analysis results provide critical information for developing sustainable development strategies that are based on the conservation and management of natural resources. Analysis of various water and soil parameters explains the impact of anthropogenic activities on the watershed. Surveys and PRA activities result in the understanding of the gap areas and implementation of strong policies and governance.

6.2 Efficient ways to replicate the outcomes of the fellowship in other parts of IHR

- Multi-hazard susceptibility mapping can be replicated for other districts of IHR which have the repeated history of one or more than one natural disaster
- Hazard zonation maps can be developed at ward level wherein the wards can be ranked high to low hazard susceptible areas.
- Hazard inventory at ward level could be developed having details on the type/scale of the hazard, date and impacts.
- In depth research on gender roles including more in depth qualitative or quantitative methods research can be carried out at ward level to gather micro level information on gender roles in disaster and watershed management.
- Survey results provide ways of capacity building in the area of disaster and watershed management. Stakeholders and their roles and responsibilities could be mapped and trainings could be provided to the local communities to cope up with the challenges identified in disaster and watershed management.

- Awareness programs could be conducted for the local communities and visitors about various issues pertaining to the sensitivity of the Himalayan environment.
- Gaps in the current disaster management plans could be identified at the district level.
- Extensive research on the impact of the anthropogenic activities on natural disaster frequency and probability.
- The people perception about the impact of infrastructural development in the IHR could be documented
- Developing disaster specific and area specific disaster resilience /disaster management plan.

6.3 Identify other important areas not covered under this study, but needs further attention

Early warning system: Early warning systems have proven to be effective in predicting natural disasters and providing advance warning to communities, allowing them to take appropriate actions to reduce the risks and damages caused by disasters. The efficiency of early warning systems, however, depends on various factors such as the type of natural disaster, the quality and timeliness of data used for prediction, and the effectiveness of communication and response systems.

Watershed restoration strategies: Watershed restoration has numerous benefits, including improving water quality, enhancing biodiversity, and providing ecosystem services such as flood control, carbon sequestration, and recreational opportunities. It can also provide economic benefits through increased tourism and improved fisheries and wildlife habitats.

Wireless Emergency Alerts (WEA): WEA is a public safety system that sends text-like messages to mobile devices in the affected area to warn people of imminent threats to safety.

Disaster resilient ecotourism: Disaster resilient ecotourism involves developing and promoting ecotourism activities and destinations that are prepared for and able to recover from the impacts of disasters. It is an approach that aims to balance the economic benefits of tourism with the need to protect the environment and the local community, and to reduce the vulnerability of IHR to disasters.

Health Hazards: In addition to major natural hazards such as landslides, floods, and earthquakes, health hazards in Himalayan cities must also be documented. Climate change and rapid urbanization have altered disease dynamics over the last few decades, increasing the occurrences of vector-borne diseases such as Dengue, Malaria, and others. Studies and climate models must be developed in order to predict and warn the public (early warning systems) about the health hazards.

Climate change: Climate change studies in the Indian Himalayan Region (IHR) are of critical importance for several reasons:

Vulnerability to climate change impacts: The IHR is one of the most vulnerable regions in the world to the impacts of climate change due to its unique geography, ecology, and socio-economic characteristics.

It is experiencing changes in temperature, precipitation, snow and glacier melt, and extreme weather events, which are impacting its ecosystems, water resources, agriculture, and livelihoods.

Biodiversity and ecosystem services: The IHR is home to a rich diversity of plant and animal species, and its ecosystems provide critical services such as carbon sequestration, water regulation, and soil conservation. Climate change is threatening these ecosystems and their services, which have implications for both local and global environmental sustainability.

Water security: The IHR is the source of several major rivers in South Asia, including the Indus, Ganges, and Brahmaputra, which provide water for millions of people. Climate change is affecting the timing and quantity of river flows, which can lead to water scarcity and impact the livelihoods and well-being of communities in the region.

Food security and agriculture: The IHR is an important agricultural region, producing crops such as rice, wheat, and maize. Climate change is affecting the availability of water for irrigation, as well as the incidence of pests and diseases, which can impact crop yields and food security.

Adaptation and resilience: Climate change studies in the IHR can help identify adaptation and resilience strategies for communities and ecosystems to cope with and recover from the impacts of climate change.

6.4 Major recommendations for sustaining the outcomes of the fellowship in future (500 words in bullets)

- Learn more about and emphasize the role of women and men in emergency management planning and messaging;
- Engage in more in-depth research on gender roles, including more in-depth qualitative or mixed methods research that uses interviewing and/or focus group methodologies on gathering more in-depth information at ward level
- Develop strategies to empower women, educate men, and promote the genders working together synergistically to prepare effectively while also perhaps, at the same time, overcoming gender stereotypes.
- Promote gender-sensitive preparedness by using networks that appeal to and advocate for women, including those that have a long history of assessing and addressing public health issues (e.g., women's social and health care providers).
- Use a range of communication channels for increasing hazard knowledge and preparedness, including gender-related scenarios or case studies that appeal to people and promote empowerment and working cooperatively together within households and communities.

- Include natural hazard education in children's school curricula (e.g., education on gender empowerment and cooperation in the context of creating a current and future population that has resilience and risk management knowledge and skills) with the purpose to prepare for and solve problems linked to a range of risk scenarios in life such as natural hazards.
- Based on the current quantitative research, there is an increasing need for more gender-focused mixed methods research to contextualize gender discrepancies in more depth and at a local scale.
- Doing so can better target and tailor disaster management planning and preparedness, response, and recovery education campaigns. Such work could result, perhaps even quite significantly, in fewer victims of natural hazard events, lessening economic losses, and reducing other consequences.

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APPENDICES

Appendix 1 – Copies of Publications Duly Acknowledging the Grant/ Fund Support of NMHS
Appendix 2 – List of Trainings/ Workshops/ Seminars with details of trained resources and dissemination material and Proceedings

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(Signature of HRA)

(Signature of HJRF)

(**NMHS FELLOWSHIP COORDINATOR**)
(Signed and Stamped)

(**HEAD OF THE INSTITUTION**)
(Signed and Stamped)

Place: New Delhi
Date: 27/03/2023