सत्यमेव जयते

INTEGRATED FARMING SYSTEM FOR FOOD SECURITY IN INDIAN HIMALAYAS UNDER CLIMATE CHANGE

A Case Illustration of Upper Kosi Catchment in Kumaun Himalaya



A Research case study taken under the project
Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES)

Supported by Department of Science and Technology Government of India

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Resilient India - Disaster free India

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MESSAGE

The Department of Science & Technology (DST) serves as a nodal agency for coordinating two of the eight missions under National Action Plan for Climate Change, viz., National Mission on Sustaining the Himalayan Ecosystem (NMSHE) and National Mission on Strategic knowledge for Climate Change (NMSKCC). DST constantly working towards fulfillment of the objectives and targets set out under these two missions.

Under the National Mission on Strategic Knowledge for Climate Change (NMKSCC), which aims at enhancing the ability of national knowledge systems to deliver effective response towards climate change, DST is providing support to number of research programmes on human and institutional capacity building on areas related to climate change across different research institutions in the country.

DST is extremely glad to support one such human capacity building programme "Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES)" under the mission NMSKCC at the National Institute of Disaster Management (NIDM). The project employs a holistic approach which builds on science, policy and practice framework for addressing the existing knowledge and capacity gaps related to climate change and climate risk management.

The present study carried out under the project CAP-RES, under the leadership of Prof Anil K. Gupta, brings out a comprehensive case illustration highlighting need for resilient agricultural systems as a crucial component for overall climate change adaption strategies particularly in Indian Himalayan region where agriculture remains one of the important economic activities. The integrated farming systems as proposed under the study provides a well-formulated operational framework for climate resilient livelihood system for the mountain communities; helping them in enhancing their capacities and building resilience towards climate change and climatic-induced disaster risks. I am sure that the study will be highly useful for a broad range of stakeholders from policy, research, practice and academia.

(Akhilesh Gupta)

Resilient India - Disaster Free India

Maj. Gen. Manoj Kumar Bindal
VSM
Executive Director

सत्यमेव जयते

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FOREWORD

As the climate change begin to manifest itself in form of increased intensity and frequency of disaster events such drought, floods, storms, and extreme temperatures incidences; there lies an urgent need for enhancing the capacities of communities for addressing climate change and the associated disaster risk. Also, it becomes extremely important to develop a holistic understanding of climatic induced risk and vulnerabilities and integrate them well within the disaster risk management planning and practices across all the levels.

The project CAP-RES funded by Department of Science & Technology, Govt. of India aims promoting science- policy- practice framework based capacity building towards different aspects of climate change and associated disaster risks by enhancing the knowledge and training support systems on the subject. The project focuses on five key thematic areas viz. Green Growth and Disaster Risk Reduction; Resilient Agriculture; Resilient Health; Climate proofing during Disaster Relief and Recovery; and Policy Instruments in DRR. One of the key approaches advocated under the project emphasis on undertaking field based analysis across each of the five themes. These field-based studies would help in capturing the region and climatic-hazard specific challenges and opportunities across these themes. The key findings of these field based case illustrations not just provide an opportunity for knowledge disseminations and advancement but can also contribute towards policy planning processes, policy advocacy and training-capacity building programmes.

The present research case study carried out under the project focuses on resilient agriculture theme of the project and examines the impact of climate change and climate induced disaster risks on food and livelihood security in Indian Himalayan Region of Uttarakhand. Further, the study explores on a framework for climate resilient integrated farming systems for improving the food and livelihood security in the region by employing an integrated watershed management approach. The study helped in bringing out some valuable insights and important recommendations for policy planners, local governance institutions and communities for developing and adopting climate-resilient framework and strengthening mountain agricultural systems.

MK Bindal

(Manoj Kumar Bindal)

Resilient India - Disaster Free India

Prof. Anil K Gupta

Head-Environment,
Climate and Disaster Risk Management
Division & Project Director, CAP-RES

सत्यमेव जयते

राष्ट्रीय आपदा प्रबंधन संस्थान
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About the Research Study

The present study is carried out under the sub-theme on 'Resilient Agriculture' of the major interdisciplinary Research Project titled 'Climate Adaptive Planning for Resilience and Sustainable Development in Multi Hazard Environment' (CAP-RES) funded by the Department of Science and Technology (DST), Government of India, New Delhi and being implemented by National Institute of Disaster Management (NIDM), Government of India, New Delhi. The present study has been undertaken by engaging the expert collaborator Dr. P.C. Tiwari, Head- Professor and Head-Department of Geography, Kumaun University, Uttarakhand.

The present work illustrates on the case study of Indian Himalayan Agricultural systems. The prime objectives of the study have been: (i) to analyze the impacts of changing climatic conditions, particularly rainfall variability and extreme weather events, and to assess their impacts on community food security; and (ii) to evolve a framework for the development of climate change and natural disaster resilient integrated farming system employing the approach of integrated watershed management, with a view to help evolving and implementing various climate change adaptation and disaster risk management action plans by the government line departments at local levels. The two rain-fed watersheds - Ramgad Watershed and Kosi Headwater - have been selected from for the case illustration from Kumaon Lesser Himalaya. The impacts of changing climatic conditions, particularly rainfall variability and extreme weather events, on agricultural system and community food security have been studied in Ramgad Watershed; whereas the Kosi Headwater (Watershed) has been found appropriate for the development of climate change and natural disaster resilient integrated farming system.

The report in hand tries to present a detailed account of the research and scientific work as a part of study and is divided into four main Chapters. Chapter - 1 presents the rationale, background and objectives of the study. Chapter - 2 discusses in detail the methodological framework adopted in the study. Chapters - 3 and Chapters - 4 which constitute the core part of the work, respectively presents the results drawn in the form of observation, key inferences and conclusion; and strategic recommendation including technical findings, methodological lessons and take away for policy makers respectively. The case study report makes a thorough assessment of the impact of climate change on agricultural resources, farm productivity and community food security; and provides a framework for the development of climate change and natural disaster resilient integrated farming system at watershed level. At last this report provides with an Executive Summary for Policymakers discussing conclusions derived along-with a road map of future action plan for the implementation of the outcomes of the project.

(Anil K Gupta)

PREFACE

In Himalaya, the constraints of terrain, climate, infrastructure, markets, technologies, and information impose severe limitations on productivity of agricultural resources and efficiency of infrastructure and services. This compels a large proportion of rural population to practice subsistence agriculture as a means of survival. The rapidly transforming climatic conditions has stressed traditional agricultural and food system through higher annual mean temperature, altered precipitation pattern, and increasing frequency and severity of extreme weather events which are adversely affecting the food and livelihood security in Himalaya. The long-term impact of changing climatic conditions would certainly change the conditions for food production through influencing irrigation potential, soil properties, cropping patterns, crop rotation, cropping strength, and cropping intensity; and as a result, increase the vulnerability of weaker sections of society to the increasing risk of food insecurity.

Capitalizing upon both the socio-cultural and biophysical strength of the mountain landscape, integrated farming systems have the potential to contribute significantly towards attaining food and nutrition security as well as improving and diversifying livelihood opportunities for mountain communities under climate change. However, this underlines the need of integrating agricultural adaptation strategy into the overall process of natural resource development that involves efficient utilization of natural, human, financial and technical resources particularly at local levels.There is no doubt that agriculture is going to be one of the important components of sustainable development framework and climate change adaptation strategy in Himalaya in time ahead. It is therefore, highly imperative that climate resilient agriculture should constitute one of the core elements of the overall natural resource development process, climate change adaptation strategy and disaster reduction framework in Himalaya. Since, the mountain agriculture relies on the utilization of land, water, forests and biodiversity resources which are inter-dependent in nature; watershed provides the most ideal natural unit for the development of climate resilient farming system and its mainstreaming with integrated natural resource development programmes.

The main objective of the work focuses on analyzing the impacts of changing climatic conditions, particularly rainfall variability and extreme weather events, and assessing their impacts on agricultural and food system. The study also attempts to evolve a comprehensive framework for climate resilient integrated farming system, and integrate it into integrated watershed management programmes involving local government departments, village institutions and local communities with a case illustration of Kosi Headwater and Ramgad Watershed regions in Kumaon Himalaya, Utarakhand.

Prof. P. C. Tiwari

ACKNOWLEDGEMENT

The research case study on “Development of Integrated Farming for Improving Food Security in Himalayas under Climate Change: A case Illustration of upper Kosi Catchment in Kumaun Himalaya, Uttarakhand,” is carried out under the Project Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES) supported by Department of Science & Technology (DST), Government of India. A special note of thanks to Dr. Akhilesh Gupta, Advisor & Head SPLICE and Climate Change, DST, GoI for entrusting NIDM with the opportunity to take up and work on the CAP-RES project. The project team is thankful to Major General Manoj Kumar Bindal, Executive Director NIDM for his constant support and encouragement for undertaking the study and ensuring the smooth functioning of the project.

The contributions of the expert collaborator Dr. P.C. Tiwari (Professor and Head of the Department of Geography, Kumaun University) and his team comprising of Dr. Bhagwati Joshi, (Assistant Professor, Department of Geography, Government Post Graduate College, Rudrapur, Uttarakhand), Mr. Dheeraj Pant and Mr. Vaseem Ahmad (Ph.D. Researchers, Kumaun University) are acknowledged for joining hands with us in undertaking this study which takes into account both technical understanding and policy interventions at the same time.

From CAP-RES team, coordinated Ms. Shweta Bhardwaj (Research Fellow) for the case study. Thanks are also due to the CAP-RES team including Dr. Sweta Baidya (Research Associate), Ms. Pritha Acharya (Research Fellow) and Ms. Thinles Chondol (Young Professional). The project team also extend thanks to Shri S.K. Tiwari (Librarian, NIDM) and the entire publication cell of NIDM including Ms. Sonali Jain and Ms. Karanpreet Kaur for helping in printing and publication of this report.

Prof. Anil K Gupta
Project Director
CAP-RES Project

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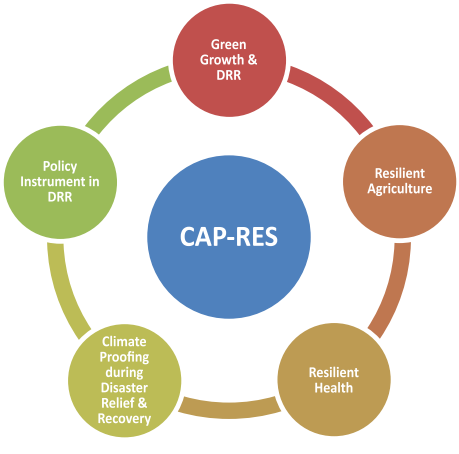
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CONTEXT

Centre for Excellence on Climate Resilience (CECR at NIDM)

National Institute of Disaster Management (NIDM) has a dedicated Division on Environment, Climate change and Disaster Risk Management (ECDRM) which has been designated as a Centre of Excellence on Climate Resilience (CECR) under the National Action Plan for Climate Change and Human Health (NAPCCHH). The CECR is implementing five research projects namely Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES) with support of DST-Govt of India, National Agriculture Disaster Management Plan (NADMP) funded by the Ministry of Agriculture & Farmers Welfare, Health Resilience and Capacity Building (HER-CAP) with WHO, Crisis Management Plan for Dealing with Contamination of Water Bodies (CMP-WB) funded by CPCB, Disaster Management Plan for Ministry of Environment, Forest and Climate Change (NEFC-DMP) with MOEFCC, National Disaster Management Plan of Dept. of Chemicals and Petrochemicals (NCP-DMP) supported by MOC&F. It also collaborates with a number of international and national organizations working in the areas of climate change adaptation and resilience with reference to disaster risk reduction

About CAP-RES



Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES) is an umbrella project which tries to address the gap areas in capacity building to curb the challenges of climate change. The project encompasses five thematic areas: a) Green Growth and DRR; b) Resilient Agriculture; c) Resilient Health; d) Climate proofing during disaster relief and recovery; and d) Policy, Instruments in DRR. CAP-RES focuses across three specific regional contexts, i.e. Indian Himalaya Region (special reference to North East), Coastal region and Central western region. Region specific climate related hazard complex, including flood, drought, water scarcity, forest fire, cyclone/storm surge, coastal erosion, slope erosion/ landslide, windstorms, heat wave, disease epidemics, industrial/chemical risks, etc.

Extended Abstract

About the theme: Resilient Agriculture Systems

Agriculture sector is one of the most disaster affected sectors. It is adversely affected by weather changes/ variations in physical conditions resulting in huge economic losses and disruption of people's livelihood. The increasing frequency and severity of climate related hazards and risks induced by climate change are adding a new dimension to the existing disaster risk profile of India. There is an immediate need for integrated disaster risk reduction strategies, strengthening the agriculture systems in the country and making them more resilient towards future disasters and climate change consequences. For making agriculture resilient foremost requirement is quantification of losses and damages in terms of production, assets, post- harvest impact for different allied sectors (crops, livestock and fisheries) which can actually help in prioritizing the focus areas for policy interventions.

In Himalaya, the rapidly changing climatic conditions and climate change induced natural disasters have stressed the traditional agricultural system. The food security in the region primarily depends on local agricultural productivity and community food purchasing power. The changing pattern of rainfall and increasing frequency and severity of extreme weather events have drastically reduced food production, decreased rural livelihood opportunities, and consequently increased the vulnerability of large proportion of rural population to food insecurity. It has been observed that both the average rainfall and the total numbers of rainy days have decreased drastically over the last 20-30 years. At the same time, the frequency and severity of cloud-bursts and meteorological droughts have shown steadily rising trends across the region. These changes in climatic phenomena are disrupting hydrological cycle of the Himalayan watersheds and decreasing irrigation potential. As a result, agronomic production is declining and livelihood opportunities in traditional farming sector are decreasing which are affecting both availability of and access to food in the vast rural areas. Moreover, climate change has increased the frequency and severity natural disasters which are altering the conditions for food production in Himalaya through influencing cropping pattern, crop rotation, cropping strength, and cropping intensity; and thus increasing the vulnerability of local communities, particularly poor and marginalized sections of rural population to food insecurity.

Himalaya provides one of the best examples of integrated mountain farming system evolved through thousands of years of community-experimentation with fragility, inaccessibility and marginality and resultant low carrying capacity of natural resources. However, during the recent past the traditional mountain farming system have eroded considerably mainly due to population growth, rural-outmigration, rapid urbanization, depletion of natural resource base, economic globalization, market influences and climate change. However, capitalizing upon both the biophysical strength and socio-cultural capital of the mountain landscape the integrated farming system could contribute significantly towards attaining the prime UN Sustainable Development Goals (SDGs) of 'Zero Hunger' through sustained agricultural productivity in Himalaya under climate change. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification as well as integration of entire farming system, including agriculture, horticulture, floriculture, dairying, fishing, bee-keeping and forestry at watershed level. The study clearly indicates that integrated framing system has the potential to contribute significantly towards strengthening the adaptive capacity of local communities to climate change as well as to climate change induced natural disasters through sustained food production in Himalaya.

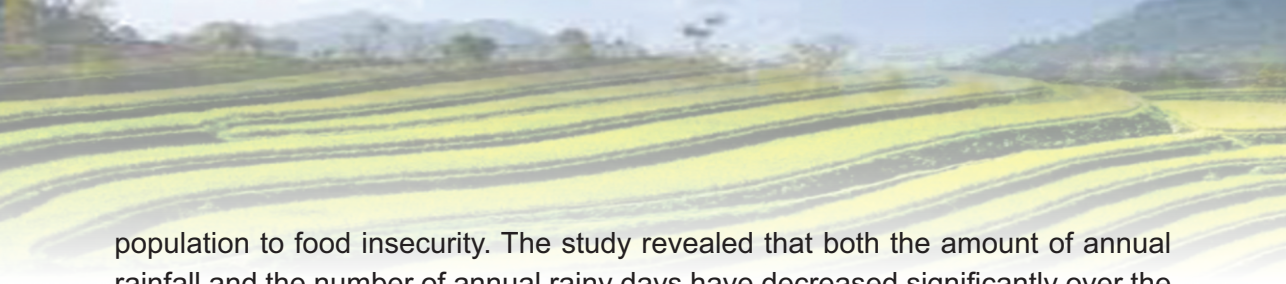
However, as recommended by NITI Aayog, Government of India; Food and Agricultural Organization (FAO) of the United Nation (UN); and the recommendations of the UN Conference on Sustainable Development, Rio De Janeiro, Brazil (Rio 1992) the mountain regions should adopt integrated watershed management approach; and climate resilient farming system should be an integral component of integrated watershed development programmes. Further, the mountain agriculture need to be integrated with ongoing various poverty reduction schemes, food and livelihood improvement programmes, women's empowerment projects; and rural employment schemes as well as with ecological restoration and climate change adaptation action plans. Moreover, integration of different sectors of mountain economy with local agricultural production system, flow of credit to rural areas, and increased investment on mountain agricultural enterprises will help in making mountain agriculture economically viable, ecologically conducive, and adaptive to climate change and natural disasters. This would require connecting disciplines, and thus promote coherence, consistency between agricultural and climate change adaptation policies, research, financial investments and sustainable development programmes.

Executive Summary for Policy Planners

Mountain agriculture and food security are core issues that can contribute positively to the achievement of the Sustainable Development Goals under climate change. In view of this, the sustainable development of agriculture deserve special attention for attaining the goal of Zero Hunger in Himalaya: Firstly, it is the most densely populated mountain of the planet with severe constraints to the productivity and carrying capacity of natural resources, and very high magnitude of rural poverty; and Secondly, the livelihoods of most Himalayan dwellers depend heavily on agriculture with little or no option to sustain on other viable sources. This clearly underlines the urgent need of strengthening Himalayan agriculture and food system under rapidly changing climatic condition and increasing severity and risks of climate change induced natural disasters.

Himalaya represents one of the geographically complex, economically underdeveloped and densely populated mountain ecosystems. The geo-environmental constraints strictly limit the carrying capacity of natural ecosystem as well as productivity of agricultural resources. Consequently, forest-based subsistence agriculture constitutes the prime means of livelihood and food security for more than 70% of the rural population in the area. In the recent past, a series of environmental and socio-economic factors, such as increase in population, rapid urbanization, growth of tourism and land use intensifications have transformed the traditional agricultural and food system across the Himalayan Mountains. As a result, land use pattern has changed and critical agricultural resources have depleted and degraded. Moreover, the changing climatic conditions and climate change induced natural disasters have altered the natural resource base and the conventional farming practices through rise in temperatures, changes in precipitation patterns, hydrological imbalances and increasing frequency, intensity and severity of weather-extremes over the Himalayan landscape.

In Himalaya, food security mainly depends on local agricultural productivity. This is further determined by community food purchasing power, and infrastructural facilities for transportation and distribution of food. The climate change, particularly the changing pattern of rainfall and increasing frequency and severity of extreme weather events have drastically reduced food production, decreased rural livelihood opportunities, and consequently increased the vulnerability of large proportion of



population to food insecurity. The study revealed that both the amount of annual rainfall and the number of annual rainy days have decreased significantly over the past 19 years, and the occurrence of cloudbursts and droughts have increased in the region. These changes have destabilized the hydrological regime and decreased the availability of water resources resulting into decline in irrigation potential, recurrent crop-failures, and decline in farm- productivity and livelihood opportunities for rural communities in conventional agricultural and forest sectors all across the region. Moreover, the climate change has increased the frequency and severity of natural disasters, particularly flash-flood, landslides and drought which are changing the conditions for food production in Himalaya through influencing the cropping pattern, crop rotation, cropping strength, and cropping intensity; and thus increasing the vulnerability of local communities to food insecurity. This will have long-term impacts on food security of nearly 75% rural population. The segment of population which is highly vulnerable to food insecurity mainly includes poor households, women, landless and socially marginalized people; marginal and small farmers and persons without any regular source of income.

Himalaya provides one of the best examples of integrated mountain farming systems evolved through thousands of years of experimentation with fragility, inaccessibility and marginality and resultant low carrying capacity of natural resources. However, during the recent past the values of traditional farming system have eroded considerably mainly due to population growth, rapid urbanization, depletion of natural resource base, economic globalization and market influences and climate change. However, capitalizing upon both the socio-cultural and biophysical strength of the mountain landscape integrated farming system has the potential to contribute significantly towards attaining food and nutrition security as well as securing viable livelihood opportunities for mountain communities under climate change. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification and integration of agriculture, horticulture, floriculture, dairying, fishing, bee-keeping and forestry at watershed level. The study clearly indicated that integrated framing system has the potential to contribute significantly towards strengthening the adaptive capacity of local communities to climate change as well as to climate change induced natural disasters through sustained food production and improving food security in Himalaya.



However, as recommended by the Food and Agricultural Organization (FAO) of the United Nation (UN), and the recommendations of the UN Conference on Sustainable Development, Rio De Janeiro, Brazil (Rio 1992) the mountain regions should adopt integrated watershed management approach; and climate resilient farming system should be an integral component of integrated watershed development programme. Further, the mountain agriculture need to be integrated with ongoing various poverty eradication programmes, food and livelihood improvement strategies, women's empowerment and gender mainstreaming schemes; and rural employment schemes as well as with ecological restoration and climate change adaptation mechanism. Moreover, integration of different sectors of mountain economy with local agricultural production system, flow of credit to rural areas, and increased investment on mountain agricultural enterprises will help in making mountain agriculture economically viable, ecologically conducive, and adaptive to climate change and natural disasters. This would require connecting disciplines, and thus promote coherence, consistency between agricultural and climate change adaptation policies, research, financial investments and sustainable development programmes.

Chapter - 1
Introduction

1.1 Background

Mountain regions extend over approximately 24% geographical area of the planet (United Nations 2012; UNEP-WCMC 2002); and nearly 12% of the global population live in mountains. Mountain regions constitute source of freshwater for nearly 70% of the World's population (FAO, 2019a; FAO, 2019b; Viviroli et al. 2003 and 2007). However, mountains constitute highly sensitive ecosystems (ICIMOD 2018), and they are extremely susceptible to the impacts of ongoing processes of global environmental changes, specifically climate change and related natural disasters (Sonesson and Messerli, 2002; Tiwari, 2000; ICIMOD, 2018). Subsistence agriculture with livestock raising constitute the main source of food and livelihood of mountain communities (ICIMOD, 2010; Roberts, 2009). However, Approximately 75% of the geographical area of the mountain regions of the world is not suitable or marginally suitable for crop production (Huddleston and Ataman, 2003), and as a result, the large population living in the high mountains of developing and less developed countries is poor and vulnerable to all types of environmental changes, particularly climate change (Huddleston and Ataman, 2003). It has been observed that the poverty-gap between mountains and their adjoining lowlands has increased significantly over the last some decades (ICIMOD, 2009 and 2007). Consequently, mountain peoples are among the world's poorest, marginalized, and food insecure, and their voices are often unheard. Nearly 40% of the mountain population living in the high elevation zones in developing and poor countries have been estimated to be highly vulnerable to food insecurity (Huddleston and Ataman 2003; FAO, 2008, 2015 and 2018).

The global environmental changes and consequent process of natural resource development have not only depleted and degraded the fragile environmental components of mountains, but also posed serious challenges to the social, cultural and economic sustainability of mountain people (Tiwari and Joshi, 2015b). Over the past some decades, population growth, development of tourism, economic globalization, and rapid urban growth have emerged as most powerful drivers of environmental changes in mountain regions. These drivers have transformed the conventional resource utilization pattern and caused the massive depletion and

degradation of natural resource base in mountains all over the world. (Ouyang, 2012; Hauenstein et al. 2010; FAO, 1997; Messerli and Ives 1997). Consequently, the natural, social and cultural systems of mountain areas are changing fast leading to over-exploitation of their critical natural resources, such as, land, water, forests, biodiversity. These changes are threatening the socio-ecological sustainability of both the mountains and densely populated lowlands, particularly in developing countries (Rasul, 2019; Sati, 2016; FAO, 2008, 2015 and 2018). Furthermore, the rapidly changing climatic conditions are undermining the efficiency of a range of ongoing development programmes, particularly targeted to poverty reduction and improvement of livelihood opportunities in mountain areas of developing and poor countries (UNDP, 2010). Moreover, these changes may weaken the intrinsic ability of mountain people to respond and adapt to changing environmental conditions, particularly climate change (Tiwari and Joshi, 2020 and 2019; Huddleston and Ataman, 2003; FAO 2008b and FAO, 2008c).

Outside the polar areas, the Himalayan Mountains and the adjoining Tibetan Plateau put together have the largest land surface under glaciers and permafrost on the earth (ICIMOD, 2018). The large glaciers, snow-covered slopes and forested watershed form the headwaters the some of the biggest trans-boundary river systems of the earth. Himalaya being tectonically alive densely populated and inhibited by some the poorest and marginalized people constitutes one of the most fragile ecosystems of the planet (ICIMOD, 2018). It represents geographically varied, geologically complex and biologically unique ecosystems and a range of environmental services flowing down from the Himalayan river systems and landscape contribute towards the economic sustainability of nearly 44% global population living in the densely populated vast plains of South Asia (ICIMOD, 2010). In Himalaya, the geo-environmental constraints limit the productivity of natural resources and restrict the carrying capacity of fragile ecosystem. As a result, the availability of cultivable land is limited and productivity of natural resources is significantly low, and subsistence farming is the prime source of food and livelihood for the majority of rural population (ICIMOD, 2010). As a result, Himalaya constitutes the home of some of the poorest and marginalized people of the world. In view of this, the Himalayan communities are particularly susceptible to food insecurity mainly because of their high dependency on natural resources, subsistence economy, low productivity, physical isolation and, vulnerability to natural risks, poor infrastructure, limited access to markets and higher cost of production (Tiwari and Joshi, 2019). Food and Agricultural Organization of the United Nations observed

that a large proportion of food insecure population lived in mountain regions of the world and nearly 245 million rural populations living in world-mountains was vulnerable to food insecurity (Huddleston et al., 2003, FAO, 2008). The low carrying capacity of subsistence agriculture compels a large proportion of male youths to out-migrate the villages to find viable means of livelihood for the survival of their families. The remittances sent by the migrated population constitute the principal source of cash income and food purchasing power of majority of the rural population in the region (Tiwari and Joshi, 2019).

Currently, the traditional natural resource utilization system is passing through the process of rapid transformation primarily due to increase in population, urban growth, development of tourism infrastructure, construction of large number of hydropower projects, globalization, land use intensifications and climate change in Himalaya (ICIMOD, 2018; Tiwari and Joshi, 2019; 2012a and 2012b). These changes have stressed the mountain subsistence production practices through depletion of natural resource-base and disruption of traditional integrated farming system. This is undermining the adaptive capacity of the mountain socio-ecological system to increasing risks of climate change and climate change induced natural disasters (ICIMOD, 2010). Furthermore, the climate change has destabilized the sensitive natural ecosystem of the Himalayan ecosystem by rise in annual mean temperature and mounting variations in spatio-temporal pattern of precipitation; and increasing occurrence of climatic extremes, particularly prolonged winter and spring droughts and high intensity rainfall. The impacts of climate change and variability have deepened the impacts of natural, social and economic stressors (ICIMOD, 2018; IPCC, 2014; UNEP-WCMC, 2002). The climate observations clearly show a warming trend, although at different rates and in different periods depending on specific regional and seasonal circumstances (ICIMOD, 2018).

The economy of Himalaya is predominantly rural and highly dependent on climate-sensitive sectors such as biomass-based subsistence farming, horticulture and livestock enterprises (Tiwari et al., 2019). The increasing variability in rainfall and rising annual average temperature are transforming hydrological regimes and modifying the soil moisture conditions, particularly in rain-fed Lesser Himalayan Mountains (ICIMOD, 2018). Eventually, these changes are affecting agricultural production, food security, and livelihood opportunities (Government of Uttarakhand 2014). The entire region being tectonically alive environmentally sensitive is highly vulnerable to a variety of natural hazards and disasters; moreover the raising trends of extreme weather events have increased, frequency, intensity and severity natural

disasters, particularly, high intensity rainfall, flash-floods, landslides and droughts disrupting the traditional subsistence agricultural and food system in the entire region (Grainger et al., 2021; Tiwari and Joshi, 2019 and 2020). Furthermore, the changing hydrological characteristics of these extreme events, in relation to the onset, duration are affecting agricultural production significantly. The region is likely to experience rising temperatures and changing precipitation patterns in coming years; and may experience more intense rainfall and more frequent, intense droughts and other extreme weather events (World Bank, 2018). The impacts of climate change would not only undermine the critical agricultural resources, such as land, water, forest and biodiversity; but also increase the vulnerability of large population, particularly poor, marginalized and weaker sections of the society to food and nutrition security across the regions (ICIMOD, 2018; World Bank, 2018). It is therefore highly imperative to revive, strengthen and develop the integrated farming as one of the integral components of the overall climate adaptation strategy at watershed level in Himalaya.

1.2 Literature Review

Himalaya includes the largest areas covered by glaciers and permafrost outside the polar regions of the planet (ICIMOD, 2018). It constitutes source of a range of ecosystem services, such as, freshwater, soils, and biodiversity that support life and economic sustainability of some of the poorest people of the planet inhabiting the large plains of the Ganges, Indus and Brahmaputra rivers (Scott et al., 2019; World Bank, 2018; Woodroffe, et al. 2006). Himalaya being the highest, tectonically alive, and densely populated and inhibited by some the poorest and marginalized people constitutes one of the most sensitive ecosystems and climate change hot-spots of the planet (ICIMOD, 2009).

In Himalaya, merely 15% of the total geographical area is available for agriculture, consequently, biomass based subsistence agriculture with very low carrying capacity is the major means of rural economy for more than 70% population (ICIMOD, 2007). High dependency on climate sensitive natural resources and low efficiency of infrastructure and services, particularly in densely populated middle Himalayan ranges is escalating rural poverty and socio-economic marginalization. This is undermining the sustainability of traditional farming and food system, threatening food security, and increasing the vulnerability of large population to the intensifying impacts of climate change (Huddleston and Ataman, 2003). Declining agricultural productivity and loss of livelihood opportunities in farming sector are

increased the trends of male out-migration leading to feminization of mountain agriculture and farming system (Tiwari et al., 2019; Tiwari and Joshi, 2012a and 2012b). The remittances sent by the migrated population constitute the principal source of cash income and food purchasing power of majority of the rural population across the Himalayan Mountains.

Climate change have destabilized the Himalayan agro-ecosystem by increasing the average annual temperature and retreating glaciers, fast melting of snow, modifying precipitation system, and increasing climatic extremes. The intensifying impacts of climate change and climate change induced natural disasters have further deepen the impacts of other drivers of environmental changes, underdevelopment and marginalization (IPCC, 2014, 2007a and 2007b; UNEP-WCMC, 2002). Climate change is disrupting the hydrological regimes of the Himalayan watershed and modifying the discharge, volume and availability of water and increasing frequency and severity of extreme events both in mountains and lowland (ICIMOD, 2018). Thus, the climate change has undermined the conventional farming mountain economy and food production system through depletion of land, water, biodiversity and forests resources; and increasing frequency and severity of climate change induced natural disasters (Dimri et al., 2011). This has collapsed the conventional farming system through frequent crop failures and steady decline in food productivity, and increased vulnerability of large population, particularly poor and weaker sections of the society to food insecurity (ICIMOD, 2009). The rapidly changing climatic phenomena and climate change induced natural risks have further increased the trends of rural out-migration. This has weakened the social sustainability and increased the vulnerability of rural women to climate change and climate change induced natural risks (Tiwari and Joshi, 2012b). As a result, a large proportion of population is becoming highly vulnerable to water, food, livelihood and health insecurity both in the Himalayan Mountains and the plains of South Asia. Moreover, this will also have enormous regional implications for all range of ongoing developmental programmes, and even to peace and security in the entire South Asia (World Bank, 2018).

Food security is defined as a condition that exists when the entire population of a geographical region has physical, social and economic access to adequate, safe and nutritious food that meets its dietary needs, nutrition requirements, and food preference for an active and healthy life at all times (Food and Agricultural Organization 2003; Fullbrook 2010)). The access to sufficient and nutritious food is determined by various geo-environmental and social, cultural and economic drivers

that vary spatially as well as temporarily in different parts of the world (Barrett, 2010). The global food security situation has been continuously deteriorating mainly because of population growth and resultant increasing demand of food, encroachment of productive agricultural land by rapid urbanization and industrialization particularly in developing countries, declining per capita agricultural land, disruption of ecosystem services, and depletion of natural resources (Food and Agricultural Organization, 2008a and 2008b). Further, the food production is also facing stern challenges from the rapidly changing environmental conditions, such as desertification of large proportion of productive lands in most parts of the world, particularly in densely populated developing countries (Meybeck et al., 2001). It has been estimated that more than 1 billion people in the world have no access to sufficient food, and nearly 2 billion people are suffering from micronutrient deficiencies (Barrett, 2010; Sonesson and Messerli, 2002). Moreover, climate change is acting as additional and stringent stressor and accelerating the multiple impacts of existing socio- economic stressors on global agricultural and food system (Food and Agricultural Organization, 2008a and 2008b). Further, the global food productivity may decline between 3% and 16% by 2080 due to climate change (Cline, 2008). The developing and less developed countries are likely to face severe food crisis owing to their large population and subsistence agricultural economy than the developed countries in the era of climate change (Food and Agricultural Organization, 2008a and 2008b). India is expected to face decline in food production up to the extent of 30% by 2080 due climate change (Cline, 2008; Aase et al., 2013 and 2009).

1.2.1 Mountains and Food Security

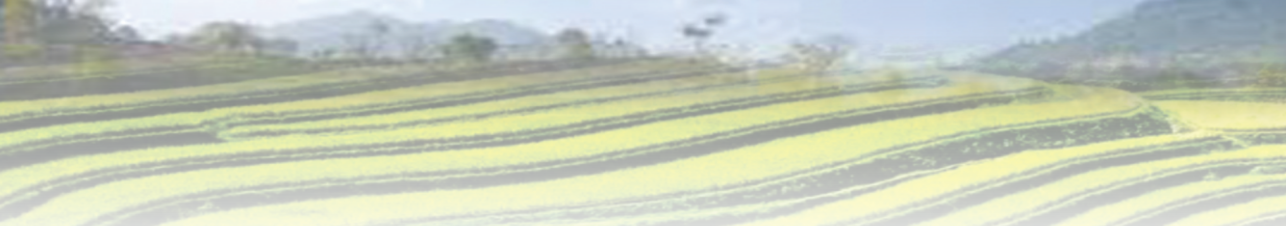
Mountain regions constitute source of freshwater for nearly 70% of the World's population (FAO, 2019a and 2019b; Viviroli et al., 2003 and 2007). However, The mountain ecosystems are characterized by fragility, sensitivity and marginality that render them highly susceptible to all kinds of natural and socio-economic changes including climate change and all kinds of natural risks (Sonesson and Messerli, 2002; Tiwari, 2000; ICIMOD, 2018). Subsistence agriculture with livestock rising constitutes the main source of food and livelihood of mountain communities (ICIMOD, 2010; Roberts 2009). Owing to geo-environmental constraints less than 25% land surface is suitable for agricultural practices (Huddleston and Ataman, 2003), and consequently the poverty level generally increases with rising altitude (Huddleston and Ataman, 2003). It has been investigated that the gap in poverty

between mountains and adjoining plains have increased over the past some decades (ICIMOD, 2009 and 2007). Consequently, mountain peoples are among the world's poorest, marginalized, and food insecure, and their voices are often unheard. Nearly 40% of the mountain population living in the high elevation zones in developing and poor countries have been estimated to be highly vulnerable to food insecurity (Huddleston and Ataman, 2003; Food and Agricultural Organization, 2008, 2015 and 2018).

At present, the ongoing processes of global environmental change have posed serious threat to the sustainability of mountain ecosystems as well as to the well being of mountain people, particularly in the developing world (Tiwari and Joshi, 2015b). The ongoing process of economic globalization, rapid urbanization, and increase in population in high mountains have transformed the pattern of natural resource utilization in most of the mountain regions of the world, particularly in Himalaya (Ouyang, 2012; Hauenstein et al., 2010; FAO 1997; Messerli and Ives, 1997). Consequent upon this, the natural environment, society, economy and culture of high and densely populated mountains of the world, specifically Himalaya have been transforming fast posing severe challenges to socio-ecological sustainability both in up-streams and down-stream areas (Rasul, 2019; Sati, 2016; Food and Agricultural Organization, 2008, 2015 and 2018). Moreover, the intensifying impacts of climate on fragile socio-ecological system of the mountain regions are undermining the process of socio-economic development and increasing poverty, marginality and gender gap (UNDP, 2010). This is weakening the adaptive capability and traditional coping mechanism of mountain people to climate change (Tiwari and Joshi, 2020 and 2019; Huddleston and Ataman, 2003; FAO, 2008b).

1.2.2 Himalaya: The Hot Spot of Climate Change

Himalaya includes the largest areas covered by glaciers and permafrost outside the polar regions (ICIMOD, 2018). It represents the most diverse and complex mountain ecosystems which sustain the livelihood of nearly 44% of the population of the planet (Scott et al., 2019; World Bank, 2018; Woodroffe et al., 2006). It forms the source of some of the biggest trans-boundary rivers of the earth that drain the most densely populated mountains and the plains of the planet (ICIMOD, 2010). Himalaya being the highest, tectonically alive, and densely populated and inhibited by some the poorest and marginalized people constitutes one of the most sensitive ecosystems and climate change hot-spots of the planet (ICIMOD, 2009). The



fragility of natural ecosystem, and limited carrying capacity of natural resource base, scarce arable land, low productivity of natural resources, subsistence agricultural economy, high poverty levels, growing developmental deficits, and increasing socio-economic marginalization are increasing the susceptibility of the Himalayan communities to risks of climate change (ICIMOD, 2007; Tiwari et al., 2019; Tiwari and Joshi, 2012a and 2012b). In view of this, climate change and natural disasters have emerged as some of the additional and strong drivers of rural out- migration in Himalaya, during the recent years. The remittances sent by the migrated population constitute the principal source of cash income and food purchasing power of majority of the rural population across the Himalayan Mountains (Tiwari and Joshi, 2012a and 2012b).

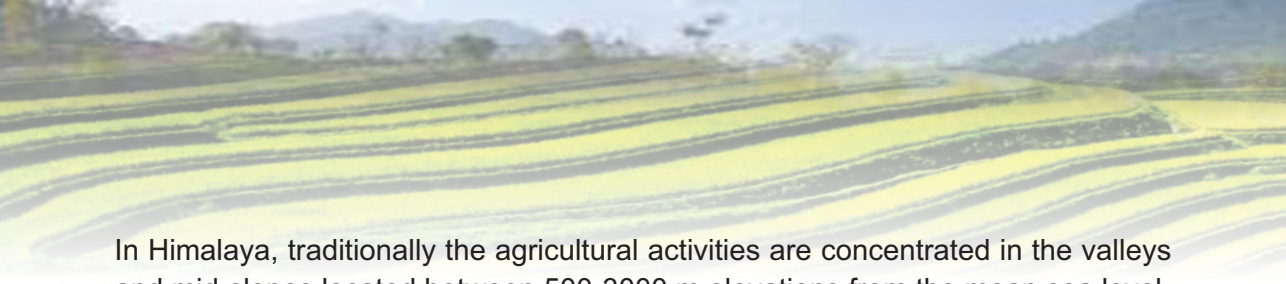
It has been observed that in Himalaya, both the rate of rise in temperature and melting of glaciers is much higher compared to other high mountain regions of the world. In view of this, Himalaya being the highly fragile and most densely populated mountain is exceedingly susceptible to the long-term impacts of climate change (IPCC, 2014, 2007a and 2007b; UNEP-WCMC, 2002). Climate change is disrupting the hydrological regimes of the Himalayan watershed and modifying the discharge, volume and availability of water and increasing frequency and severity of extreme events both in mountains and lowland (ICIMOD, 2018). These changes in climatic phenomena have stressed the traditional farming and livelihood system through depletion of land, water, biodiversity and forests resources; and increasing frequency and severity of climate change induced natural disasters (Dimri et al., 2011). This has collapsed the conventional farming system through frequent crop failures and steady decline in food productivity, and increased vulnerability of large population, particularly poor and weaker sections of the society to food insecurity (ICIMOD, 2009). The rapidly changing climatic phenomena and climate change induced natural risks have further raised the level of rural out-migration increasing gender inequality and undermining social quality of life (Tiwari and Joshi, 2012b).The climate change is not only undermining the water, food, health and livelihood security of considerably large population both in mountains and in the plains; but it is also having enormous regional implications for all range of ongoing developmental programmes in the entire South Asia (World Bank, 2018).

1.2.3 Traditional Integrated Farming System in Himalaya

Integrated farming is a comprehensive term used to describe an interconnected land, forest, water, biodiversity and livestock based production system governed by

a set of local institutions (Choudhary, 2013; Tiwari and Joshi, 2015; Tiwari et al., 2019; Taneja, 2016). It refers to agricultural and food systems that integrate crop production, livestock and other locally suited farm enterprises and conservation practices (Behera et al., 2004). Mountain farming is complex and diverse system created by multiplicity of agro- ecological conditions as well as geo-environmental constraints (Jodha, 2005). In Himalaya, integrated farming is a traditional production system since time immemorial; but in recent years, it has been elaborated as all-round development of agriculture, animal husbandry, horticulture, fisheries and other local farming systems. Integrated farming system is an economically and environmentally sound diversified production system (Behera et al., 2004). It signifies optimization of various farm components and their integration for multi-enterprise farming systems in given set of agro-ecological regime for enhanced soil health, resource use efficiencies, higher productivity and profitability and adaptation to climate change (Choudhary, 2013). In view of this, the integrated farming system is an adaptive natural resource management framework and resilient agricultural system to climate change as well to climate change induced natural disasters in mountain regions, particularly in developing and less developed regions all across the world where a considerably large proportion of population still depend on agriculture for its food and livelihood (Tiwari et al., 2019).

The Himalayan communities have developed the most complex, diverse, sustainable and integrated farming systems of the world through their experimentation with natural constraints and fragility for several thousand years (Jodha, 1997; Aase et al., 2013). The conditions of terrain and climate impose limit the productivity of bio-physical resources as well as the carrying capacity of natural ecosystem (Jodha, 2005; Maithani, 1996; Nangju, 2001; Papola, 1998; Tiwai and Joshi, 2018a). In Himalaya, the traditional agro- ecological system is constituted by forests and pastures, cattle and cultivated land. The forests and pastures are fundamental as they constitute the source of biomass energy which is essential for maintaining farm productivity (Tiwari and Joshi, 2012a and 2018b; ICIMOD, 2010). It is therefore essential to transfer the biomass energy from forest ecosystem to cultivated land to maintain the productivity capacity of land under high cropping-intensity (Singh et al., 1984; Rasul et al., 2019; Maithani, 1996). The livestock play crucial role in transferring the biomass-energy from forests and pastures to the crop-land in the form of their manure and labour (Figure 3). In Himalaya, it has been analyzed that nine units of biomass energy is required to obtain one unit of agricultural production from the cultivated land (Singh et al., 1984).



In Himalaya, traditionally the agricultural activities are concentrated in the valleys and mid-slopes located between 500-3000 m elevations from the mean sea level. There are mainly three types of farming systems in Himalaya (Tiwari et al., 2019): (i) Crop Livestock Farming System: This is the most common and widely practiced agricultural system across the Himalayan mountain between 500 and 2500 m elevations which overlap with the most densely populated parts of Himalayan mountains. Cultivation of a variety of food and cash crops both with and without irrigation with livestock rearing are the main characteristics of this farming system. Livestock are natural ally of mountain framing system as they not only connect crop production with forests and rangelands and mediate the flow of biomass energy from forest and grassland to agriculture; but also constitute the main source of food, livelihood and nutrition security and income to mountain communities; (ii) Livestock Farming System: This system prevails in higher Himalaya from 2500 m to above 5000 m mainly is the Western Himalayan Sates of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and also in some parts of North Eastern Himalaya. Sheep and goat flocks are reared on natural pastures in the Alpine zone mainly by indigenous communities with transhumance as common practice. In this system various animal products are exchanged and sold for food and income generation. In order to ensure food and nutrition security under low carrying capacity of natural resources the farmers also grow vegetables, root crops and a variety of lentils in the marginal lands particularly during summer month at higher elevations (Choudhary, 2013); and (iii) Shifting cultivation: Shifting cultivation or slash and burn agriculture is a very common form of farming system practiced across the North East Himalaya. In this system a piece of land is cultivated until the soil-nutrients and fertility decline, and then left abandoned for some years allowing the land to replenish; and cultivation is shifted to another piece of land (Ansari et al., 2014). This is in fact the most comprehensive agro-ecological system ensuring food and nutrition security through the production of a range of crops, fruits, vegetables and livestock production system including piggery, poultry and fisheries; and conserving agro-biodiversity (Bahera et al., 2004; Yadav et al., 2013).

1.3 Context

1.3.1 Observed Trends in Climate Change

Historically, the Himalayan climate has experienced significant changes that are closely related to the rise and fall of regional cultures and civilizations since time immemorial. The climate of the Himalayan Mountains exhibits diverse geographical variability, which is closely linked to the varied topography (Scott et al., 2019). The region has experience significant warming in the past decades nearly equal to the global average. As recorded in the past decades, Elevation Dependent Warming (EDW) is expected to be observed widely in future projections in the region. During the last 120 years, Himalaya has experienced warming from 1901 to 1940; cooling from 1940 to 1970; and again warming from 1970 to 2020. In Himalaya, the annual mean surface temperature has shown an average increase of approximately 0.10 °C per decade during 1901 - 2014, while the warming rate has been 0.2 °C per decade over the last 50 years (Krishnan et al., 2019). The recent trends of global warming clearly indicate that the rate of warming is much higher in Himalaya compared to other mountain regions of the world. It is expected that, in the future, even if global warming is kept to1.5 °C, the annual average temperature in Himalaya most likely be at least between 0.3 °C and 0.7 °C higher at the end of the century (Krishnan et al., 2019). This large increase in temperature could trigger a multitude of biophysical and socio-economic impacts, hydrological disruptions, loss of biodiversity, fast glacial melting, and less predictable water availability. These changes likely to have severe adverse impact water, food, livelihoods and community health in the Himalayan Mountains and their vast and densely populated lowlands in South Asia (World Bank, 2018).

Himalaya is experiencing increasing variability in western disturbances which bring nearly 20% of the annual rainfall in winter and spring month (Krishnan et al., 2019) Besides global warming, other regional forcing elements like anthropogenic aerosols and land-use changes appear to have influenced the pattern of South Asian monsoon and precipitation variability during the last almost 70 years. It has been observed that the annual precipitation undergoes a clear shift after 1990 in the region (Krishnan et al., 2019). The temporal characteristics of precipitation variation appear to have entered a mode of greater inter-annual variability and more frequent intense rain and less frequent light rain. A significant increase in annual mean daily precipitation intensity over past decades appeared in the higher altitude areas in

Himalaya. The climate change has also increased the frequency and severity of extreme weather events in Himalaya during the last 5-6 decades. The region has shown a rising trend of extreme warm events; a falling trend of extreme cold events; and a rising trend in extreme values and frequencies of temperature-based indices. It has been investigated that the number of cold nights decreased by 1 night per decade and the number of cold days decreased by 0.5 days per decade, while the number of warm nights reduced by 1.7 nights per decade and number of warm days raised by 1.2 days per decade (Krishnan et al., 2019). It is expected that these changes in climatic extremes will continue and pose even more serious challenges to climate change strategies in the region.

1.3.2 Himalayan Agriculture: Spectacle of Subsistence

The Himalayan agriculture is broadly defined as covering all land based activities such as cropping, animal husbandry, horticulture, and forestry, as well as water conservation and a variety of natural resource management practices owing to their organic and functional linkages (Figure 1). However, the main problems of Himalaya have their roots in the peculiar geographical conditions and the resultant physical and human constraints. As mentioned in the preceding sections the Himalayan farming system is characterized by low productivity and high cropping intensity, and people practice agriculture in highly compelling circumstances. The availability of arable land is strictly limited (less than 0.2 ha per person), but the dependency levels for food and livelihood are considerably high. (Figure 1). More than 90% land holding size are of less than one hectare, and only approximately 11% of total cultivated land is irrigated, and average per capita availability of arable is less than 0.2 ha (Tiwari, 2012a). The limited supporting capacity of subsistence economy increases the cropping intensity up-to the extent of as much as 168%, and that forces increasing number of rural youth to migrate out of the mountains to find means livelihood (Maithani, 1996).

1.3.3 Specificities of Himalayan Agriculture

The performance as well as the pattern of the Himalayan agriculture is determined and shaped by a set of complex and interconnected specificities that include, inaccessibility, fragility, marginality, diversity, niche and human adaptation mechanism to these elements (Jodha, 1997). These phenomena present a range of opportunities and constraints for agriculture in mountains, and also influence human responses to them. The important specificities of the agriculture in Himalaya are as follows:

Limited Accessibility: The poor accessibility of farm land in mountain areas is largely attributed to the slope, altitude, terrain conditions, and seasonal hazards as well as lack of proper investment to overcome this inaccessibility. The lack of accessibility results in isolation, remoteness, semi-closeness, and poor mobility and high cost of mobility; limited access to, and dependability on external support (products, inputs, and resources).

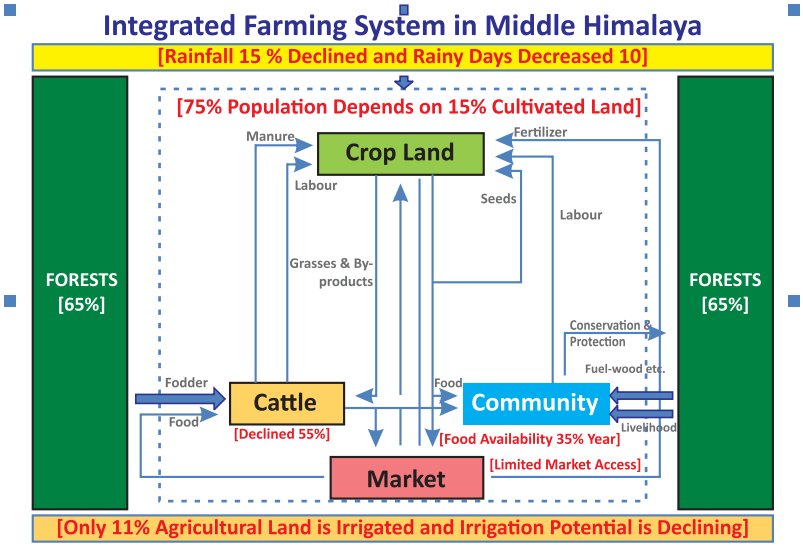


Figure 1. Integrated Framing Systems in Himalayas

Fragility and Marginality: Tectonic instability, increasing altitude, steep slope, and sharp climatic variability and resultant biophysical constraints have rendered Himalaya physically fragile and socio-economically marginal. This results in low carrying capacity of natural ecosystem, poor productivity of agricultural resources and decreased efficiency of infrastructural facilities.

Diversity: Diversity in mountain agriculture is the product of interactions between various physical parameters and anthropogenic elements. This influence the spatial pattern of production and consumption activities; results in limited scale-associated benefits; and requires territorial diagnosis followed by diversified interventions and decentralized arrangements (technologies, infrastructure, and institutions).

'Niche' Opportunities: The diversified natural conditions of mountains consisting of varying biophysical conditions and resource characteristics create niche. Niche offers unique potential for a variety of natural resource and indigenous knowledge

based production systems, such as hydropower generation, agriculture, livestock, fish, bee- keeping, horticulture and medicinal herbs with significant comparative advantages. Harnessing of 'niche' should constitute an integral part of diversified farming and food system using the capital of traditional practices, modern science and technology, infrastructural support and community participation.

1.3.4 Constraints to Agricultural Development

In Himalaya, traditionally the agricultural activities are concentrated in the valleys and mid-slopes located between 1000-2200 m elevations from the mean sea level. There are mainly three types of farming systems in Himalaya: (i) livestock farming, (ii) mix livestock-crop farming, and (iii) mix crop-livestock farming. The agricultural land which in fact represents an extensive form of agri-silvi-horticultural system, accounts for nearly 8.3% of the total geographical area of Himalaya. In Himalaya, a considerably large proportion of population depends on limited natural resources with limited carrying capacity, and as a result, per capita utilization of natural resources is decreasing steadily and significantly. This is very much true particularly in the case of land resource. Agriculture is one of the most dependable and primary livelihood options of the communities living in Himalaya, and this conventional agricultural system is now collapsing due to various natural and socio-economic factors throughout the region. Himalaya it is affected by high growth of human population and resultant intensive cultivation of agricultural land.

It has also been observed that by bringing more and more areas under the network of protected area is not only affecting the sustainability of mountain agriculture, but also undermining the livelihood of forest dependent rural communities in Himalaya (Tiwari and Joshi, 1997). Over the past some decades, a series of changes have emerged in the conventional resource utilization pattern in the region primarily owing to increase in population and the consequent enhanced demand of land, water, forest resources. As a result, land use pattern has changed and critical natural resources, such as, land, forest, water, and biodiversity have depleted steadily and significantly stressing traditional agricultural and food system (Tiwari and Joshi, 2018a and 2018b). Moreover, the climate change has already stressed the mountain farming and livelihood systems through rising temperatures, fast retreating glaciers, melting of permafrost and snow, increasing spatio- temporal variability is precipitation pattern, disruptions hydrological cycle and increasing frequency of weather extremes across the region. In view of this, the following constraints are posing serious threat to the sustainability of Himalayan agriculture:

Scarcity of Arable Land: The availability of arable land is severely limited in Himalaya as only, 8.3% of the total geographical area of Himalaya is under cultivation. The net sown area as percent of total geographical land surface is merely 1.4%, 3.7%, 6.3%, 11.0%, 8.45%, 3.2%, 10.1% and 13.0% respectively in the Himalayan States of Arunachal Pradesh, Manipur, Nagaland, Sikkim, Jammu and Kashmir, Himachal Pradesh and Uttarakhand against about 44% in the entire country. In spite of relatively low population density in Himalaya, the pressure on the land is very high as the proportion of net sown area is very small. With the rapid increase in population and resultant decrease in per capita availability of arable land, agriculture in the Himalayan Mountains has been extended to marginal and sub-marginal areas and those with 100% slope (Maithani, 1996). Out of the total cultivated land approximately 21% is characterized by steep slope of more than 300 and poor soils that are prone to accelerated erosion. The per capita availability of land is only 0.29 ha which is declining steadily and significantly mainly due to population growth and various other land transformation processes operating in the region. Nevertheless, in many parts of Himalaya, such as Kumaon Himalaya, the availability of per capita land is below 0.2 ha which is too small to afford sustainable livelihood in the region. As a result, the majority of land holding size is of less than one hectare (Tiwari and Joshi, 2018a).

Low Productivity: The constraints of terrain, soils, climate as well as socio-economic constrictions impose severe limitations on the level of resource productivity and efficiency of infrastructural facilities and services in Himalaya. As a result, the productivity of agriculture is considerably low, particularly in middle and upper slopes where more than 95% cultivated land is rain-fed due to acute shortage of water and its inappropriate management. On an average, the region is facing a food deficit of more than 65% which has shown consistently increasing trends during the recent past increasing the vulnerability of traditional food and agricultural systems which is having serious implications to rural livelihood improvement and poverty alleviation efforts (Tiwari and Joshi, 2012b and 2018a).

High Dependency for Food and Livelihood on Agriculture: Despite severe scarcity of agricultural land and low farm productivity the dependency on traditional agricultural system both for food and livelihood is considerably high in all parts of Himalaya. As much as nearly 75% population of Himalaya depends merely on 8% agricultural land for its food and livelihood which symbolizes distress husbandry of land. This very clearly brings out the fact that large population in the Himalayan

mountains do not have viable means of livelihood other than subsistence farming to sustain. It also shows that the traditional mountain farming system is unable to provide food and livelihood security to growing population, particularly under climate change which is transforming the natural resource base and reducing the carrying capacity of conventional agricultural system. Ironically, on the other hand, only 5% population of Himalayan mountains depends on as much as approximately 47% forest area endowed with rich biodiversity and plenty of natural resources, for its livelihood (Tiwari, 2010). Interestingly, the household level income from agriculture varies from 15% to 41% which is much lower than 31% to 53% of the total household income contributed by off-farm sectors of rural activities in Himalaya (Maithani, 1996).

Forest Based Agriculture: Forest Based Agriculture: Traditionally, the agriculture in Himalaya is a forest based primary production system which primarily relies for its energy requirements on the adjoining forests, pastures and rangelands. As mentioned in the preceding sections, the large livestock population link the forest ecosystem with the crop production process by mediating the supply of biomass energy from forests, pastures and rangelands to agricultural fields in the form of organic manure and labour. However, owing population growth and resultant land use changes the availability of forest to cultivated land is decreasing continuously leading to depletion of forest resources and un-sustainability of Himalayan agriculture.

Water Deficiency: The Himalayan mountains constitute the water tower of the earth, as its gives birth to some the biggest and largest rivers of the earth. However, so far, the available water potential could not be utilized for sustainability of agriculture and livelihood in the region. This is clearly substantiated by the fact that merely 11% of the total cultivated land is under irrigation in the region. Moreover, the regime of water resources in the Himalayas is likely to change rapidly, with respect to discharge rates, volumes and availability, primarily due to global climatic changes, as well as increasing population pressure having long term adverse impacts on the subsistence agricultural economy of the region (Viviroli et al., 2003; ICIMOD, 2007). This will have serious implications particularly in densely populated and intensively cultivated rain-fed watersheds which contribute significantly to the agricultural productivity and food security of the entire region (Tiwari and Joshi, 2012a and 2018a). Most of the Lesser Himalayan catchments are now facing severe water deficiency which is evinced by inadequate or even non-availability of water for various domestic purposes and decline of irrigated land in the region. The main

reason investigated for increasing scarcity of water for both domestic and irrigation of crops was the rapid depletion of water resources in the headwater regions (Haigh 2002; FAO 2008a and 2008b). However, it was also observed that improper management and inefficient governance of available water resources is also contributing towards increased water-stress in the region to some extent. For instance, no measures have so far been taken for converting huge amount of run-off during monsoon season into water resource, wider rain-water harvesting, and inter-catchments transfer of water (particularly transfer of water from snow-fed rivers to rain-fed water scarcity basins) for meeting the growing demand of drinking and irrigation water, and even effective strategies for replenishing, regeneration and conservation of dwindling water resources are extremely lacking in the entire region causing great hardship to local people and resulting in the underdevelopment of the entire region.

1.4 Need for study: The rationale

Himalaya provides critical ecosystem services that sustain both the upland and densely populated lowland far away from mountains (Rasul and Sharma, 2015). The mountain and lowland ecosystems are therefore largely interactive and inter-dependent forming an integrated socio-ecological system within river basin and watershed (Rasul, 2014). The most important provisioning service provided by the Himalayan ecosystem to the large population in mountains and lowland is freshwater, and therefore Himalaya is known as 'water tower' (Viviroli et al., 2007; UNEP-WCMC, 2002). The freshwater of Himalaya besides sustaining more than 200 million people living in the Himalayan mountains, supports the life and economy of more than 44% global population living in the densely populated downstream in South Asia (Viviroli et al., 2007, Tiwari and Joshi, 2014a). The Himalayan watershed regulate the hydrological processes both in upland and lowland and contribute significantly towards maintaining the water balance through ground-water recharge and storing of rain-water into surface water-bodies (ICIMOD, 2009).

However, changing climatic phenomena have disrupted the hydrological regimes of the rain-fed watersheds in the Lesser Himalaya through rise in temperature and changes in rainfall pattern which are not only increasing the frequencies and magnitudes of climatic extremes, particularly high intensity rainfall, flash-floods, floods and droughts, but also causing substantial decrease in water availability through changes in volume and discharge of water in streams and rivers both in mountains and their adjoining plains (Kohler and Maselli, 2009; IPCC, 2007a;

Beniston, 2005). During recent years, the high intensity precipitation have triggered flash floods, slope failure and landslides in Himalaya having severe impacts on the natural and socio-economic sustainability both in up-streams and down-streams ecosystems (Tiwari and Joshi, 2015b; ICIMOD, 2009). These changes are exacerbating the impacts of other socio-economic drivers of change particularly in the densely populated, intensively cultivated and rapidly urbanizing Lesser Himalayan mountains. In view of this, the Lesser Himalaya has emerged as hot spot of climate change, and climate change induced vulnerabilities and risks. Secondly, a large proportion of water discharge in the Ganga system is contributed by the watersheds and catchments of rain-fed rivers originating from the Lesser Himalayan mountains (ICIMOD, 2010). The availability of freshwater in Lesser Himalayan watersheds is under severe threat both from climate change and anthropogenic stressors. The increasing population pressure and rapid urban growth in Himalaya is not only stressing water resources in terms of demand, utilisation patterns and management practices, but also disrupting the hydrological regime of the rain-fed headwaters. The change in headwater system is affecting river flows, agriculture, forests, biodiversity and health besides creating hydrological hazards and disasters both in upland and lowlands.

1.4.1 Climate Change Adaptation and Disaster Management at Watershed Level

A watershed is a natural and hydrological unit from which water and run-off drains into a common outlet (Dixit and Wani, 2003). Further, 'A watershed is an area that supplies water by surface or subsurface flow to a given drainage system or body of water, be it a stream, river, wetland, lake, or ocean' (World Bank, 2001). However, watershed is not simply the hydrological unit but also socio-political-ecological entity which plays vital role in providing a variety of ecosystem services to population living both in up-streams and down-streams (Wani et al., 2008; Dixit and Wani, 2003). In view of this, watershed is considered and recommended as the most appropriate and scientific natural spatial unit for formulation and implementation of integrated resource management framework, climate change adaptation strategies and disaster risk reduction programmes in mountain regions (United Nations, 2012; Darghouth et al., 2008; FAO, 2006; World Bank, 2001)

1.4.2 The Lesser Himalaya

The Lesser Himalaya or Middle Himalaya is located between the Great Himalaya and the Siwalik mountains between 1500 and 2800 meters elevation from the mean sea level (Joshi et al., 1983; Joshi, 2004). The Lesser Himalayan Mountains are separated from Siwalik Hills by the Main Boundary Thrust (MBT) in the south; and from Great Himalaya by the Main Central Thrust (CBT) in the north. These tectonic junctures make the Himalayan Mountains tectonically active and sensitive to mass movements and slope instability. The Lesser Himalayan Mountains cover approximately 50% of the geographical area of Uttarakhand State. The Lesser Himalaya is mainly composed of crystallines, granites, gneisses and schist rocks (Valdiya, 1998). The region is characterized by a varied relief features consisting of deep river valleys, the ridge and mid-slope areas and the high upland slopes. The annual average rainfall in the region varies between 1000 and 1500 mm with sub-tropical, temperate to cold climatic conditions. The environmental realm of the Lesser Himalaya is marked fragility, inaccessibility, marginality and diversity. The area is highly vulnerable to a variety of natural hazards and disasters which are now being accelerated by the rapidly changing climatic conditions. As mentioned in the preceding section the Lesser Himalaya is the most densely populated, intensively cultivated the vastly urbanized mountain range of Himalaya. The large scale exploitation of natural resources and resultant land use intensifications are disrupting the natural ecosystem and hydrological regimes of watersheds in the region (Valdiya and Bartarya, 1991; Valdiya, 1987).

1.5 Scope of the study

Kosi Catchment which is one of the most densely populated, intensively cultivated and vastly urbanized areas in the Lesser Himalayan mountains of Uttarakhand have been selected as representative spatial unit of the case illustration in the present study.

The main objectives of the work are: (i) to analyze the impacts of changing climatic conditions, particularly rainfall variability and extreme weather events, and to assess their impacts on community food security; and (ii) to evolve a framework for the development of climate change and natural disaster resilient integrated farming system employing the approach of integrated watershed management. In order to attain these objectives two rain-fed watersheds located in the Lesser Himalayan ranges of Uttarakhand have been selected for case illustration, and the following works have been carried out:

- Analysis of the trends of climate change, particularly variability in rainfall through the interpretation of ground based hydro-meteorological data
- Interpretation of the tendency of extreme weather events, particularly the incidences of high intensity rainfall and droughts
- Assessment of the impact of changing climatic conditions and climate change induced natural disasters on agricultural resources
- Interpretation of linkages between the parameters of climate change and food security in rain-fed watershed
- Evolving framework for the development of integrated and climate change resilient farming system based on agro-ecological diversity at watershed level

1.5.1 Ramgad Watershed



Vegetable Farming in Upslope Terraces in Ramgad Watershed

The Watershed of Ramgad river is situated in the Lesser Himalayan ranges of district Nainital in Uttarakhand (Figure 2). Ramgad is the one of important tributary-rivers of Kosi in its middle course. The river has its source at an altitude of 2346 m near Mukteshwar situated on the northern slopes of Gagar Ranges of Kumaon Lesser Himalaya. The river flowing along a transverse course of about 26 km in south, southwest and in west direction finally joins Niglat Gad at Ratighat, which is one of the principal tributaries of River Kosi in the mountainous part of its course. The Watershed encompasses a geographical area of nearly 75.8 km2 between 1025 and 2346 m altitude. The Ramgad has a deeply dissected and tectonically controlled watershed of an immature stream (Valdiya, 1998). As a result, the terrain has immature to moderate topography. The tectonic activity operative in the region indicates that the area is still at its geomorphic rejuvenation. The geology of the region has a large impact on the physiography, geomorphology and on other terrain characteristics of this small watershed. The catchment is characterized by

diversified geological structure, terrain characteristics and geomorphic landscape which are clearly reflected in varying magnitudes of structure, slopes and their aspects, variety of soils, natural vegetation and hydrological regimes and the climatic complexities. Administratively the Ramgad Watershed extends across the three Development Blocks of Ramgarh, Betalghat and Dhari constituting a part of the mountainous tract of district Nainital. The watershed is characterized by high growth of population and integrated farming, particularly a combination of horticulture and vegetable farming. The total population of the headwater was 31645 persons in 2019, which was inhabited in 35 revenue villages.

1.5.2 Kosi Catchment: The Densely Populated and Intensively Cultivated Ecosystem



Mid-slope Settlements and Farming in Ramgad Watershed

Kosi is one of the important rain-fed rivers of Uttarakhand that drains a large part of Almora and Nainital district before entering into the Plains of Ganga in Uttar Pradesh. Kosi draining a geographical area of 1475 km^2 forms one of the largest catchments and prominent drainage system in the Lesser Himalaya of Kumaon Divisin of Uttarakhand (Figure 2). The river originates in the dense forests of the Lesser Himalayan mountains near Kausani in district Almora, and then flowing along a transverse course enters into the foothill region of Bhabar near Ramnagar in district Nainital. The entire catchment of Kosi is characterized by diversified terrain characteristics, topography and geomorphic landscapes. The structural complexities obtaining in the area have not only produced characteristics landforms of different stages, but have also evolved a polycyclic landscape system in the region (Valdiya, 1998). The catchment exhibits a variety of landforms pertaining to the various stages of the fluvial processes operative in the area. The geomorphology of the region is characterized by narrowly spaced streams, multi-cyclic river terraces, lower ridges, spurs, narrow and flat valley floors, fans, and Georges (Joshi et al., 1983; Joshi, 2004).

As in other parts of Himalaya, the traditional resource utilization structure in the catchment is dependent on forest ecosystem. The natural forests in Himalaya, therefore, carry large human population, living interspersed them. These rural communities are completely dependent on forests not only for the fulfillment of their basic resource needs, such as, fuel wood, fodder, timber, grazing and water, but also for their livelihood. The Catchment of Kosi is one the most densely populated and intensively cultivated parts of Uttarakhand and makes significant contribution both to the food productivity and food security in the region. The river is also subject to devastating flash-floods and floods that cause massive damage of life and property both in up-stream and down-stream. In order to make a comprehensive study of various analytical research parameters, two representative micro-watersheds have been selected from Kosi Catchment for the case illustration in the present work. The micro-watershed selected for the case study are: (i) Kosi Headwater, and (ii) Ramgad Watersheds (Figure 2). The impacts of changing climatic conditions, particularly rainfall variability and extreme weather events, on agricultural system and community food security have been studied in Ramgad Watershed; whereas the Kosi Headwater (Watershed) has been selected for the development of climate change and natural disaster resilient integrated farming system.

The uppermost part of Kosi Catchment, which is constituted by the source regions of the master stream Kosi and its principal tributaries – Sai Gad and Menol Gad –

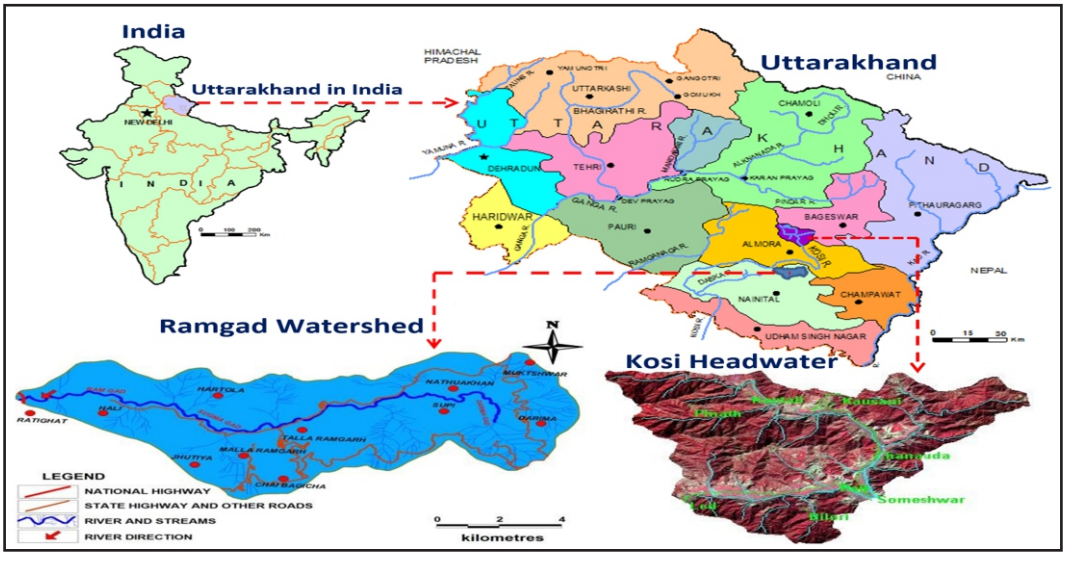


Figure 2. Location Map of Study areas

between Someshwer and the head of the watershed near Pinath, has been demarcated as the headwater region of river Kosi for the purpose of the present study (Figure 2). In this section, the headwater region encompasses a geographical land surface of 107.94 km^2 (10794 ha) the altitude ranging between 1405 – 2720 m from the mean sea level, in the Lesser Himalayan ranges of Kumaon. Administratively, the watershed is situated in Takula Development Block of district Almora which put together with 12 other districts constitutes the state of Uttarakhand. The headwater of Kosi accounts for 7.32% of the total catchment area of the river. The total length of the master stream in the region is 10 km with a fall of 1280 m.

Chapter - 2
Methodology

2. 1 Research Methods

2.1.1 Ramgad Watershed: A Case Illustration

The Study Area: Ramgad Watershed situated in the mountainous part of district Nainital, in Kumaon Lesser Himalaya, Uttarakhand has been selected as case study area for the present study (Figure 2). The Watershed extends over a geographical surface of approximately 75.8 km^2 between an altitudinal range from 1025 m to 2346 m. River Ramgad is the one of important tributaries of Kosi in district Nainital - the important rain-fed rivers of Uttarakhand Himalaya. The catchment is characterized by diversified geological structure, terrain characteristics and geomorphic landscape which are clearly reflected in varying magnitudes of structure, slopes and their aspects, variety of soils and natural vegetation, rich biodiversity, climatic contrasts and hydrological systems. Ramgad watershed is one of the densely populated tracts of the mountainous parts of Uttarakhand. In 2019, the total population of the region was 31645 persons, which was inhabited in 35 revenue villages (Figure 3). The Watershed registered almost 50% increase in population during 2001- 2019. Out of the total geographical area (75.8 km^2) of the watershed 57.71% is under forests and 25.75% is under agriculture and horticulture. The entire watershed is passing through a process of rapid environmental changes and depletion of natural resources mainly due to the intensifications of tourism and horticulture in the region. These changes are increasing the vulnerability of large population to the emerging risk of climate change and natural disasters in the entire watershed. The study area was divided up into three altitudinal transects and the same have been adopted as unit areas for the various kind of analytical studies and mapping. The three micro-watersheds of the Ramgad Watershed are: (i) Lower Elevation Zone between 1000 - 1500 m; (ii) Middle Elevation Zone between1500 - 2000 m; and (iii) Higher Elevation Zone from 2000 to 2500 m (Figure 4). The Digital Elevation Model generated using the Survey of India maps has been used for the delineation of the above- mentioned altitudinal zones. The Lower Elevation Zone, Middle Elevation Zone and Higher Elevation Zone respectively cover 15.77 Km^2 (21.02%), 37.69 Km^2 (50.25%) and 21.55 Km^2 (28.73); and 10, 07 and 18 villages of the Watershed.

Materials and Methods: Methodology included: (a) observation and monitoring of rainfall variability and extreme weather events; and (b) interpretation of inter-linkages among: (i) rainfall variability and extreme weather events, (ii) availability of water, (iii) food and livelihood security. The various primary as well as secondary sources have been used for gathering the relevant and most recent information on different research parameters included in the study. A large number of important research parameters have been analyzed through the analysis, interpretation and mapping of primary data. Comprehensive socio-economic surveys using pre-designed schedules have been conducted for generating primary data which was also supported and validated through real ground observations and mapping of spatial and temporal changes in resource utilization pattern. The secondary methods mainly included the interpretation of high resolution satellite data and analysis of large scale Survey of India (SOI) topographical Sheets of the watershed, forest resource maps, village level revenue maps (Land Record Maps); and consultation of range of available digital and printed literature. Digital interpretation techniques supported by intensive ground truth collection and intensive reconnaissance surveys have been used for the interpretation of remote sensing data.

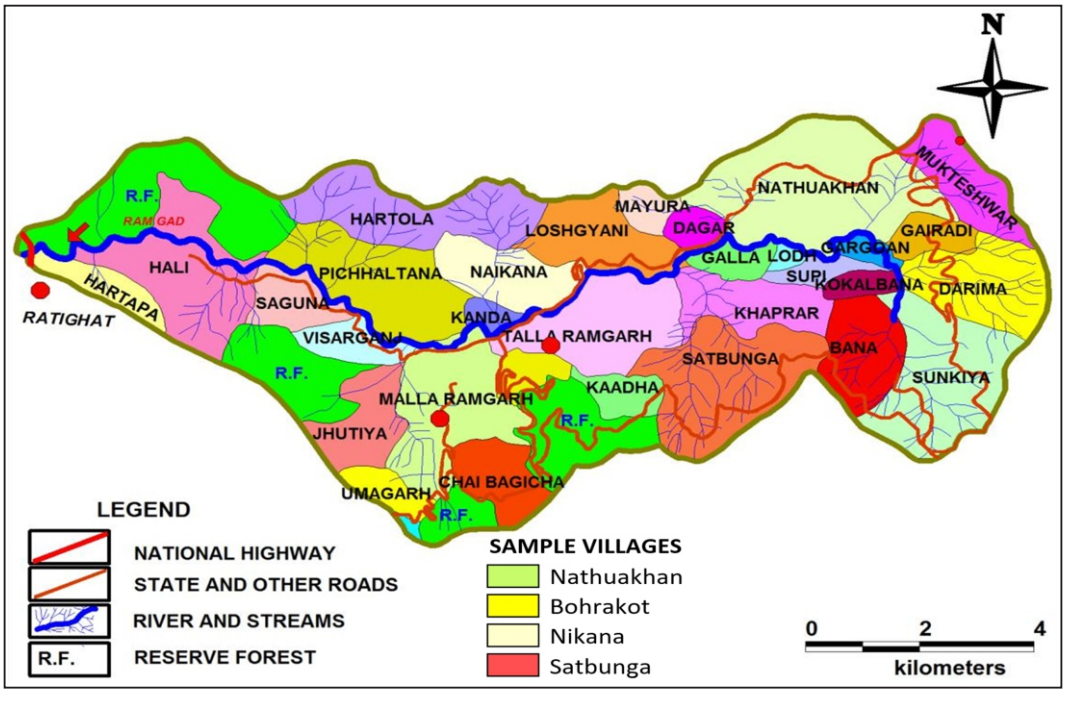


Figure 3. Distributions of Rural Settlements in Ramgad Watershed

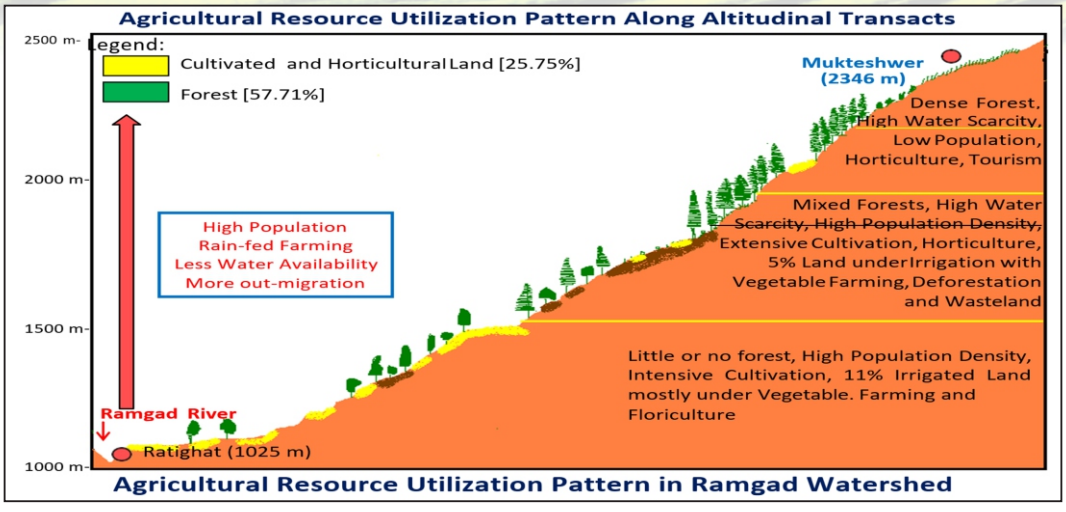


Figure 4. Attitudinal Transacts and Agricultural Resource Utilization Pattern in Ramgad Watershed.

The climatic data on various parameters including daily minimum-maximum rainfall and temperature has been collected from automated weather station of India Meteorological Department (IMD), located at Mukteshwer [which is situated on head of the watershed), and other local weather stations maintained by different government line departments. Long-term monitoring of water flow in streams and springs has been carried out for the assessment of the environmental status of water resources in the watershed. The annual mean discharge of streams and springs has been taken into account for the appraisal of water resources. In addition to the monitoring water-flow of streams and springs, a large number of elderly people across the watershed have been informally interviewed to analyze the temporal changes in the water sources of the region. The relevant primary information on various research parameters has been generated by conducting detailed household surveys in all the rural settlements of the watershed using exclusively designed schedules and questionnaires. The sample size for household surveys constituted 33% of the total households (out of total 4536 households) selecting families headed by women (25%), family living below poverty line according to the categorization of the State Government (40%), families totally dependent on farming (15%), and households who depend both on agriculture and other means of livelihood (20%). All the 35 villages of the watershed have been included in the household surveys. Elderly members of families were specifically included in the survey in order to analyze the changes that had occurred between 2001 and 2019 with respect to certain important factors, such as food production

and consumption patterns, family income, irrigated land and rural livelihood opportunities. The primary information generated through household-survey included impact of rainfall variability and extreme weather events on rural production system, water availability and irrigation potential; size of landholding, food productivity and demand, food consumption patterns, family income and food purchasing power (i.e. income from selling of agricultural and animal products, remittances sent by migrated family members and income from local employment), procurement of food, food prices and rural livelihood opportunities.

The food deficit situations were determined by estimating demand for food and its local production at village level. The food deficit was determined as the difference between production and demand, using the dietary norms recommended by the National Institute of Nutrition (NIN) (NIN, 2018) as a measure of the latter. Food security at the household level was determined as availability of food from local agricultural production and access using purchasing power as a proxy. Households which did not meet NIN norms were categorized as food insecure. The food purchasing power of households was estimated from: (i) the income of the family from various sources, such as the selling of agricultural and animal products e.g. vegetables and milk; local off-farm employment by government and private sectors in such work as forestry, agriculture and construction; remittances sent by migrated members of family; and (ii) the amount that a family could afford for buying food from market. Information about price increases of basic food commodities including wheat, wheat flour, rice and pulses during was obtained from a detailed survey of 5 % of local grocery shops as well as through household surveys. The information and data generated and collected from various sources was transformed into spatial and non- spatial databases using Geographic Information System (GIS).

2.1.2 Kosi Headwater: A Case Illustration

The present work aims to evolve a climate resilient integrated farming system for the rain-fed Middle Himalayan Ranges with a case illustration of the Headwater of River Kosi in district Almora of Uttarakhand (Figure 2). The headwater encompasses a geographical area of 107.94 km^2 (10794 ha) between 1405 and 2720 m above mean sea level. The total population of the watershed has been enumerated to be 16080 persons in 1919 which live in 65 rural settlements located mainly along the valley of the main river and its tributaries, and middle slopes. The headwater area of Kosi river constitutes one of the most heavily populated and fertile valleys of Uttarakhand with an a population density of 149 persons/km^2, rising to 469 persons/km^2 in villages. The watershed is one of the most densely populated and agriculturally

productive areas of Uttarakhand with an a population density of 149 persons/km^2, rising to 469 persons/km^2 in villages. The major land categories are forests, cultivated land and barren land. Over 75% of the population depends on subsistence agriculture. However, approximately 99% of land holdings are smaller than 1 ha, and the per capita cultivated area is merely 0.17 ha. This not only resulting into low productivity of food at the household level, but also destabilizing the economic viability of farming system in the entire watershed through increasing the trends of rural out-migration and feminization of mountain farming system. The food security in Himalaya primarily depends on local agricultural productivity and food purchasing power of local communities, and the later comes from the remittances sent by the migrated population.

Research Methods: All necessary and relevant data and information used in the study were gathered from varying and multiple sources employing both primary as well as secondary methods. Land use and agricultural resource maps were prepared using high resolution satellite data and large scale (at Scale1:50000) Topographical Maps prepared by Survey of India (SOI). The digital image processing techniques have been used for the interpretation of satellite data. The maps and information thus generated have been validated by intensive ground truth surveys. Normalized Difference Vegetation Index (NDVI) method was also employed in order to enhance the interpretation of remote sensing data. The final land use and natural resource maps have been prepared employing on-screen visual recording and rectification technique of digital image interpretation. The hydro-meteorological data and information was collected for local weather stations operated by the different agencies of the state government. The information and data generated and collected from various sources was transformed into spatial and non- spatial databases using Geographic Information System (GIS). The primary data was generated through exclusively designed village and household survey schedules. The primary survey was conducted in 10 villages located in different agro-climatic zones, and 25% households were interviewed in each of the 10 villages in the Headwater. The selection of villages and households was done on the basis of the proportion of agricultural land and productivity, land holdings size, and income level of families. Detailed data and information have been generated on various critical parameters, such as, agricultural land utilization pattern, supply of manure, food production and consumption, family income, irrigated land and rural livelihood opportunities, community perception of climate change and natural disasters and their impact on their agricultural and food system; and responses and adaptation practices evolved by local rural communities.

Chapter - 3
Results

3.1 Climate Change and its Impact on Food and Livelihood Security in Himalaya: Responses and Adaptation

3.1.1 Observations and Inferences Drawn

The results clearly indicated that climate change has stressed hydrological system of the rain-fed headwater regions in Himalaya headwaters through abnormal increase in temperatures, decrease in the amount of rainfall and decline in annual rainy days causing substantial decrease in water availability. There is widespread agreement that global warming is associated with the most severe fluctuations, particularly in combination with intensified monsoon circulations that changes the frequency and magnitude of extreme weather events and causes severe natural hazards and disasters in all parts of Himalaya (ICIMOD, 2018). The Himalayan mountain ecosystem is highly vulnerable to a variety of natural hazards and disasters which are now being triggered by rapidly changing climatic conditions (Tiwari and Joshi, 2020; ICIMOD, 2018). The changes in temperature and precipitation patterns are increasing the frequencies and magnitudes of extreme weather events, such as high intensity rainfall, flash floods, floods, windstorms, droughts Glacial Lake Outburst Flow (GOLF) (Kohler and Maselli, 2009; IPCC, 2014, 2007a and 2007b). Moreover, the global warming is likely to intensify the hydrological cycle of the Himalayan watersheds, and consequently change the frequency, intensity and severity of floods and droughts in mountains as well as in their lowlands (Beniston, 2005). During recent years, the high intensity precipitation have triggered flash floods, slope failure and landslides, and Glacial Lake Outburst Flow (GOLF) in mountainous terrain having severe impacts on the natural and socio-economic sustainability of fragile mountain ecosystems (Rangwala et al., 2020). The long-term impacts of climate change are expected to exacerbate the impacts of other drivers of change in these fragile and densely populated mountains (Wang et al., 2019). However, we still need to improve our understanding about precise impacts of changing climatic conditions on the high mountains of the world, particularly Himalaya. Further, it would also be imperative to interpret exactly the interlink-ages among the parameters of climate change and the drivers of other

processes of environmental transformation in high mountain ecosystem (ICIMOD, 2018).

Observed Temperature Pattern and Rainfall Variability

The analysis and interpretation of long-term climatic data for the period 2001 - 2019 revealed that the annual average temperature has been increasing in the Ramgad Watershed. The temperature is particularly increasing during the winter and spring season between November to March with more increase in night temperature than the day temperature (Figure 5). As in other parts of Himalaya, the distribution of rainfall in Ramgad Catchment mainly depends upon, altitude, slope-aspect and alignment of mountain ridges. Physiographic diversities and altitudinal variations play important role in determining the quantity of rainfall at different locations. The higher amount of rainfall is recorded along the south facing slopes which comes first into the contact of monsoon winds. Generally, it has been observed that the amount of rainfall increases up to an altitude of 2100 m, but rapid decrease in rainfall is recorded on ascending above this height as with increasing altitude the supply of moisture from the ground to the air is cut-off (Joshi et al., 1983). In Ramgad Catchment the average annual rainfall ranges between 90 mm with mean monthly rainfall ranging between 11 mm in the month of November and 230 mm in the month of August.

The rainfall pattern is governed by south-west monsoon, and nearly 80% of the total annual rainfall occurs during monsoon season normally between 15 June and 15 September. The observed pattern of annual rainfall and the trend of annual rainy days have been presented in Table 1. In general, on an average the annual average rainfall has recorded a rising trend in the region during 2001 - 2019 (Figure 5). However, it is interesting to observe that the increase in annual rainfall is mainly due to rise in the incidences of heavy to very heavy rainfall in the monsoon season, particularly in the month of August and September (Figure 5). The total annual rainfall has shown a consistently declining trend during 2001 and 2019 except in the years 2004 (2200 mm), 2008 (2970 mm), 2010 (3500 mm), 2018 (2340 mm) and 2019 (2550 mm) when the entire region experienced abnormally high rainfall during monsoon season, and in winter and early spring months in 2018 and 2019. Table 1 shows that in general the amount of annual rainfall indicated a declining trend particularly between 2001 and 2017 when the total annual rainfall decreased from 2400 mm to 1115 mm. This clearly indicates that on an average the amount of

annual rainfall has been decreasing continuously in the Watershed during the last 19 years with a few exceptions (Table 1).

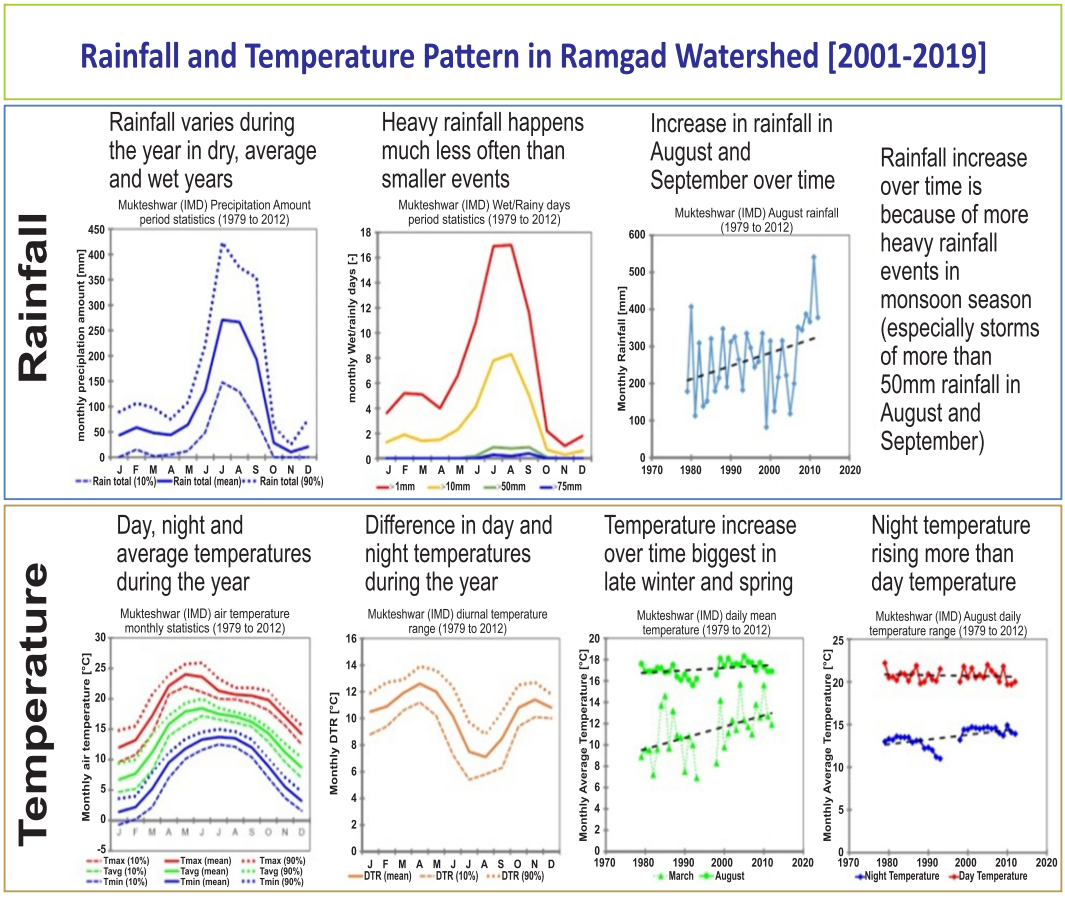


Figure 5. Rainfall and Temperature Pattern in Ramgad Watershed (2001-2019)

Temporal Distribution of Rainfall

The temporal distribution of rainfall is very critical as it directly affects the seasonal groundwater recharge, availability of rainfall during different cropping seasons and availability of water for irrigation. The temporal distribution of rainfall has been analysed through the interpretation of rainy days in the region. The overall distribution of rainy days in Ramgad Watershed during 2001 - 2019 has been presented in Table 1. The Table makes it clear that in general there is progressive decline in number of rainy days in the region during the period. The interpretation of hydro-meteorological data synthesized in Table 1 shows that the number of annual rain- days have decreased from an average of 85 rainy-days to approximately 56 rainy-days with only a few exceptions during 2001 - 2019 thus bringing an overall decline of 34% rainy days in the Watershed during the last 19 years. The lowest number of rainy days during the period (i.e. between 2001 and 2019) was recorded in the years 2008 and 2013 when rainfall occurred respectively on only 55 and 56 days (Table 1). During 2003 – 2009 the number of rainy days fluctuated between 65 and 56, whereas in 2010 the number of rainy days increased abruptly to as many as 62 and devastated the entire region by incidences of high intensity rainfall and flash floods during the peak monsoon month of September in 2010. These observations make it clear that due to considerably small number of rainy days per year the duration of sunshine would be very high resulting in high radiation and high-energy intake from the sun, in the region. This in turn would increase the rate of evaporation during dry season and cause high evapo-transpiration during the monsoon leading soil moisture loss and frequent agricultural droughts.

Table 1. Observed Rainfall Variability and Extreme Weather Events

Years	Total Annual Rainfall (in mm)	Annual Number of Rainy Days	Days of High Intensity Rainfall	Incidences of Droughts (Villages)
2001	2400	85	04	02
2002	2125	93	04	00
2003	2010	89	03	01
2004	2200	71	07	05
2005	1915	65	09	09

2006	1870	67	11	09
2007	1700	62	14	11
2008	2970	55	15	17
2009	1635	56	14	21
2010	3570	62	17	27
2011	1610	56	21	31
2012	1605	57	25	30
2013	1155	56	07	05
2014	1150	55	09	07
2015	1150	54	08	07
2016	1125	54	10	09
2017	1115	50	11	08
2018	2340	69	09	04
2019	2550	77	09	05
Average	**1905**	**65**	**11**	**11**

Pattern of Weather Extremes

The interpretation of hydro-meteorological data revealed that the high intensity rainfall and droughts have emerged as major climatic extremes in the region between 2001 and 2019. As in other parts of Himalaya, the observed changes in precipitation pattern have increased the frequency, severity and the intensity of extreme weather events, particularly the high intensity rainfall and droughts in the region. It clear from Table 1 that the frequency of high intensity rainfall has increased from merely 4 in 2001 to as many as 25 in the year in 2012, during peak monsoon months in the region. Moreover, the incidences of high intensity rainfall recorded an increasing trend between 2013 and 2019 (Table 1). The interpretation of droughts revealed that the entire region experienced severe droughts conditions during the last 19 years. Drought is generally referred to as the deficiency in precipitation over an extended period that often results in a water shortage causing adverse impacts

on vegetation, livestock, and people. Climate change induced droughts have been emerging as one of the major threat to subsistence farming system and rural livelihood in the rain-fed Lesser Himalaya (Singh and Bengtsson, 2005; Shresta et al., 1999). Drought stresses, in combination with poverty, marginality, gender imbalances, and marginalization of poor and disadvantaged groups have made smallholders more vulnerable to climate change. Drought can lead to severe harvest failures with major implications for agricultural producers and the food security of communities all over the world. The adverse-effects of drought are not only felt directly where climate extremes occur, but also indirectly in that regions suffer from the repercussions of reduced exports and higher food prices (Eckstein et al., 2019).

In the present work the incidences of droughts have been analyzed village-wise as per record of droughts maintained by the concerned government department. Table 1 shows the number of villages affected by drought during 2001 and 2019. A close observation of Table 1 clearly indicates that the number of villages affected by droughts have increased during the last 19 years in the Watershed. Out of the total 35 villages only 2 were affected by severe droughts in 2001; whereas, respectively 31 and 30 villages faced severe droughts in the years 2011 and 2012. Moreover the number of drought affected villages was between 5 and 9 during 2013 and 2019. On an average 11 villages were affected by droughts during the last 19 years (2001 - 2019) (Table 1). The interaction with local communities made it very clear that the frequency and severity of droughts have been observed increasing during winter and spring month in the Watershed during the period between 2001 and 2019. The study brought out the fact that the climate change induced droughts have been emerging as one of the major threats to subsistence farming system and rural livelihood in the rain-fed Lesser Himalaya (Krishnan et al., 2019). Further, it has been observed that the increasing frequency and duration of droughts, in combination with poverty, marginality, gender imbalances is undermining the sustainability of traditional subsistence farming system, and destabilizing the indigenous coping mechanism of communities across the Himalayan mountains (Adhikari, 2018).

Climate Change Induced Natural Disasters



Agricultural Land Devastated by Flash Flood

The increased incidences of high intensity rainfall are resulting into hydrological disruptions, flash floods and slope instability and thus triggering landslides in the catchment in Himalaya (Tiwari and Joshi, 2020; ICIMOD, 2018). The watershed being tectonically alive and environmentally sensitive is highly vulnerable to these changes in rainfall pattern, and consequent hydrological disruptions which have increased severity and frequency of landslides. The increasing incidences and intensity of flash-floods and landslides have disrupted the socio-ecological sustainability of the densely populated middle Himalayan mountains (Wang et al., 2019; World Bank, 2018). The watershed was devastated by on an average by incidences of 22 flash floods and 47 landslides every year during the last 19 years (Table 2). The region is experiencing prolonged winter [November - February] and spring [March - April] drought due to steady decline in the amount of average annual rainfall and decrease in annual rainy-days. Table 2 shows that on an average 11 villages of the region faced drought during 2001 - 2019. Increasing incidences of slope failures and landslides are not only devastating productive agricultural land and damaging conventional irrigation system, but are also disrupting road network which constitutes the only means of food-supply across the region. The increasing incidences of flash floods and resultant landslides, debris and mod-flow on an average devastated 8.63 ha of productive agricultural land, damaged a road transportation network of 14.31 km and destroyed 4.46 km of irrigation channels in Ramgad Watershed during 2001 - 2019 (Table 3). During the recent years, the increasing incidences and severity of high intensity rainfall and droughts have emerged as major factors of crop failure in as many as 12 villages every year undermining agricultural productivity and food security of considerably large population in the watershed (Table 2).

These climate change induced natural disasters not only devastated about 145 ha of productive agricultural land and declined nearly 24% agricultural production, but also undermined the food security situation of large proportion of local population by restricting food import up to the extent of 35% due to prolonged disruption of road transport in the region during the last 19 years (Table 3). This clearly indicates that increasing frequency and severity of weather extremes are undermining the food and livelihoods security of rural communities, particularly the weaker sections of the society in the watershed. Long-term impacts of these changes are likely to increase vulnerability of regional population to food insecurity through substantial decrease in production, and availability of and access to food (World Bank, 2018). Further, it was investigated that with a few exceptions the number of households affected by extreme weather events had been increasing between 2001 and 2019 distressing 680 families during the period. However, it was important to note that out of total households affected by hydrological disasters the proportion of families with agriculture as the only means of livelihood was the highest (59%). This clearly indicates the more the options of livelihood less the vulnerability to natural risks.

Table 2. Incidences of Droughts, Flash Floods, Landslides and Crop Failures

Years	Incidences of Flash Floods	Occurrence of Landslides	Incidences of Crop Failures (villages)
2001	21	14	02
2002	11	11	00
2003	11	27	00
2004	09	31	06
2005	10	35	11
2006	17	55	10
2007	24	55	10
2008	27	61	15
2009	35	65	17
2010	47	77	17
2011	55	75	21

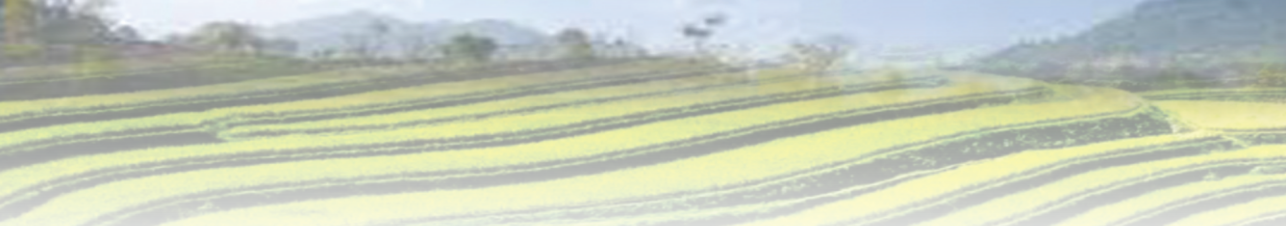
2012	57	77	20
2013	07	21	11
2014	11	35	17
2015	17	37	19
2016	21	57	21
2017	19	57	25
2018	09	55	05
2019	07	57	04
Average	**22**	**47**	**12**

Impact on Water Resources



Dried Hand Pump

Since, Ramgad Watershed is situated in the Lesser Himalayan ranges; the maximum proportion of the precipitation in the watershed is received in the form of rainfall (Joshi et al., 1983; Government of Uttarakhand, 2014). The rainfall thus constitutes the basis of the surface and sub-surface water resources in the region. As a result, streams and springs constitute the principal sources of water in the catchment. It was observed that the changes in rainfall pattern over the last 19 years and the resultant disruption of the hydrological system has contributed significantly towards depletion of water resources in the region (Panwar, 2020; Tiwari and Joshi, 2012a). The hydrological imbalances have been observed in the forms of: (i) decline in groundwater reserve, (ii) drying of natural springs and decline in water-flow, (iii) decrease in the water discharge in streams, and (iv) drying of streams (Rawat, 2009).



Recent hydrological investigations carried out in Kumaon Himalaya revealed the fact that the average groundwater storage level in the region was nearly 12% as against the recommended norm of minimum (Rawat and Rawat, 2020; Scott et al., 2019; Tiwari and Joshi, 2014a, 2014b, 2013a, 2013b and 2005; Rawat, 2009). It was investigated during the field surveys that out of total 169 natural springs as many as 47 have completely dried during the last 25-30 years. It was also observed that the average annual water discharge in the major streams of the region has reduced considerably during the last 25 - 30 years (Tiwari and Joshi, 2012a). The results of field mapping exercises and the interpretation of remote sensing data brought out the facts very clearly that sources of a large number of perennial streams have either dried or have become seasonal in the region over the past 25-30 years. As a result, a stream-length of about 1.7 km (in 6 villages located in lower elevation zone of1000 - 1500m), 2.5 km (in 5 villages situated in middle elevation zone of1000 - 1500m) and 2.9 km (in 13 villages located in higher elevation of 2000 - 2500 m) have dried during the last 30 years. Out of the total 35 villages of Ramgad Watershed 30 villages (86% villages) have been identified as facing great scarcity of water for all purposes, particularly crop production.

Impact on Irrigation Potential

In the present work the irrigation potential has been analyzed in terms of the proportion of irrigated agricultural land. Out of the total cultivated land of Ramgad Watershed (25.75 km^2) only 2.32 km^2 (9%) is irrigated, whereas 77% population is solely dependent on agriculture for its food and livelihood in the area. As in case of domestic water supply streams and natural springs constitute the sources of water for irrigation. The irrigated cultivation is mainly confined to valley floors and other low-lying areas where the regular supply of water for irrigation is available year round. The observed rising variability in rainfall pattern and resultant decline in groundwater recharge and depletion of water resources have considerably reduced the potential of irrigation system in terms of irrigated agricultural land over the past 19 years. The results of the study indicated that the irrigated area in the watershed has declined from minimum 14% to 30% in different altitudinal transacts of the region due to reduced availability of water for irrigation and resultant increased water stress during 2001 - 2019. This brought an overall decrease of about 25% in the irrigated agriculture in the watershed during the last 19 years.

Table 3. Loss of Agricultural Land, Irrigation Channels, Road Network, Food Production Food Import due to Extreme Weather Events During 2001-2019

Years	Loss of Agricultural Land (ha)	Irrigation Channels Disrupted (km)	Decline in Agricultural Production (%)	Road Network Damaged (km)	Food Import Decreased (%)
2001	03.66	2.10	11	3.40	15
2002	03.50	2.00	14	3.47	17
2003	03.79	2.70	14	3.53	17
2004	04.25	3.90	07	3.02	12
2005	04.80	3.00	08	3.00	11
2006	04.75	3.77	17	3.70	19
2007	04.90	3.50	16	4.15	23
2008	05.00	3.00	18	4.30	17
2009	06.10	5.25	21	4.77	21
2010	07.55	5.80	25	5.57	37
2011	07.25	5.65	25	27.11	35
2012	07.37	5.80	25	21.75	35
2013	11.57	5.65	39	25.79	67
2014	11.90	5.00	35	25.50	55
2015	11.77	5.15	35	25.15	54
2016	12.05	4.95	37	27.35	57
2017	11.95	5.11	37	27.45	59
2018	11.00	6.15	39	27.31	57
2019	11.79	6.25	37	25.50	55
Total	**08.63**	**04.46**	**24.21**	**14.31**	**34.89**

Agricultural Productivity and Food Deficit Situations



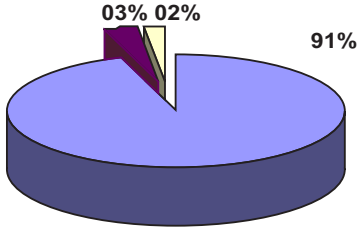
Mid-slope Agricultural Terraces

The decreasing rainfall and number of rainy days, increasing frequency of extreme weather events, particularly high intensity rainfall and droughts, depletion of water resources and the resultant loss of irrigation potential have stressed the agricultural and food systems of the region (Tiwari and Joshi, 2014a and 2014b). The interpretation of community perception of climate change and its impact on agricultural productivity and food security revealed that the pattern of rainfall in region has changed drastically and it has become erratic and the amount of rainfall decreased during the last 19 years in the Watershed (Figure 5). Further, the local people observed that erratic and reduced rainfall, and the resultant decline in water availability for irrigation have emerged as the strongest determinants decreasing agricultural productivity in the entire region (Figure 6). These sharp hydro-meteorological changes have not only decreased local food production, but also undermined rural livelihood reducing community food-purchasing power and rendering the entire region highly vulnerable to food insecurity (Heath et al., 2018). As a result, production of agriculture in the region has declined from 583 Kg/Ha/Year in 2001 to 430 Kg/Ha/Year in 2019 thus bringing a total decrease by about 154 kg/Ha/Year or 26% during the period (Table 4). With the growth of population and decline in agricultural production the per capita productivity of food has registered a declining trend over the past 2 decades. The highest decline in food production (195 kg/Ha/Year or 33%) was recorded in the Middle Elevation Zone (1500 - 2000) (Table 4). As a result, currently the different altitudinal zones of Ramgad Watershed are facing a food deficit between 78% and 88% with annual average food deficit of as much as 84% as per the food requirement norms of National Institute of Nutrition (NIN), Government of India (Table 5).

Table 4.The Status of Agricultural Productivity in Ramgad Watershed

Altitudinal Transact	Area (Km^2)	% of Total Area	Number of Villages	% of Total Villages	Agricultural Production (Kg/Ha/Year)		Decline in Agricultural Production	
					2001	2019	(Kg/Ha)	%
1000-1500	15.77	21.02	10	28.57	755	566	189	25
1500-2000	37.69	50.25	07	20.00	591	396	195	33
2000-2500	21.55	28.73	18	51.43	404	327	77	19
Ramgad Watershed	75.01	100.00	35	100.00	583	430	154	26

Bottlenecks	Community Response (%)
Irratic and Reduced Rainfall	95
Reduced Water for Irrigation	16
Labour Scarcity	03
Lack of Improved Seeds	03
Lack of Extension Services	01
Lack of Fertilizer	02



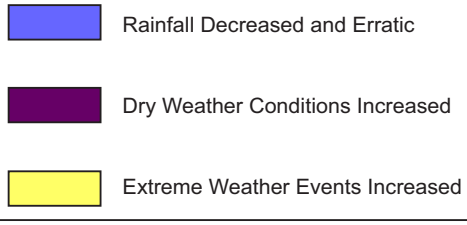


Figure 6 People's Perception of Climate Change and Constraints to Sustained Agricultural Production (2001-2019)

Table 5. Food Production, Demand and Deficit Situations in Ramgad Watershed

Altitudinal Transact	Area (Km^2)	% of Total Area	Number of Villages	% of Total Villages	Total Population	Food Production (Tonnes/ Year)	Food Demand (Tonnes/ Year)	Food Deficit	
								Tonnes/ Year	%
1000 - 1500	15.77	21.02	10	28.57	7775	191	1589	1398	88.0
1500 - 2000	37.69	50.25	07	20.00	9715	251	1773	1522	86.0
2000 - 2500	21.55	28.73	18	51.43	14155	579	2583	2004	78.0
Ramgad Watershed	75.01	100.00	35	100.00	31645	1021	5945	4924	84.0

Climate Change and Rural Livelihood

A large percentage of rural population mainly including landless households and poor and marginalized people largely depend on traditional livelihood in agricultural sector. These traditional means of livelihood mainly include village-based processing of farm and livestock products, making agricultural implements, producing traditional handcraft items, and collection of minor products forests products (non timber products) including a variety of medicinal plants and wild food which contributes to the food purchasing capacity of local communities (Joshi, 2018). The opportunities of livelihood and employment in these traditional sectors primarily depends on agricultural and livestock productivity and availability of local natural resources, mainly forests and biodiversity (Everard et al., 2018). Collection of minor forest products including medicinal plants from forests comprises one of the important sources of livelihood and income for rural poor in the watershed. However, owing to climate change and continued degradation of forests and biodiversity resources the livelihood prospects in this important traditional sector have also collapsed. In addition to these, as in other parts of Himalaya, agricultural labour, making of traditional rural handcraft and agricultural implements and processing, packaging and transportation of horticultural products constitute the major sources of community livelihood and income, particularly for the poor, landless rural artisans in the watershed. As discussed in the preceding sections the changing climatic conditions have not only destabilized traditional agricultural and food systems, but also reduced the productivity of forests, declined livestock productivity and depleted biodiversity in the region (Tiwari and Joshi, 2012b).

Consequently, the livelihood opportunities and prospects in various climate sensitive sectors have decreased considerably over the last two decades in the region. In 2001, 6747 persons were engaged in various traditional sectors, such as agro-based labour, livestock rearing, minor forest produces collection, and making of rural handicraft items and agricultural implements in the watershed. Whereas, all these sectors put together could provide livelihood only to 3780 persons in 2019. This altogether brought a decline of as much as 46% livelihood opportunities in these traditionally important rural sectors in the entire Watershed during 2001-2019 (Table 6). The maximum decline in rural livelihood opportunities (49%) was recorded in Lower Zone (1000 - 1500 m) and the minimum (41%) in Higher Elevation Zone (2000 - 2500 m) (Table 6).

Status of Community Food Security

As discussed earlier the food security in Himalaya mainly depends on local agricultural productivity, family income, availability of employment to migrated population outside the region, food purchasing power of people, and infrastructural facilities for the transportation, storage and distribution of food (Tiwari and Joshi, 2020, 2019, 2018a, 2018b, 2016, 2014a and 2012b; Tiwari et al., 2018; Mamgain, 2018; Maithani, 1996). Ramgad Watershed is facing an overall food deficit of 84% (Table 5) which is balanced by the purchase of food from the market. In view of this, development of infrastructural facilities for the transportation, storage and distribution of food, particularly during monsoon months is of critical importance for ensuring food security in the region (Tiwari and Joshi, 2015a and 2015). Unfortunately, the infrastructural facilities required for the proper and efficient distribution of food are extremely lacking as in other parts of Himalayan Mountains. As many as 45% villages in the region are still located at more than 5 km away from the nearest road, and 65% villages are located more than 7 km from the nearest market from where they can procure the food-grains. There is only one food- grain storage in the entire district which nearly 50 km away from the catchment. The inadequate and inefficient infrastructural facilities in Himalayan Mountains are posing a serious threat to food security, particularly in settlements located in remote and inaccessible areas (Rasul et al., 2019; Tiwari and Joshi, 2012b).

Table 6. Loss of Rural Livelihood Opportunities in Ramgad Watershed

Altitudinal Transact	Number of Villages	Total Population	Persons Engaged in Traditional Livelihood Sectors (in 2001)	Persons Engaged in Traditional Livelihood Sectors (in 2019)	Total Decline in Rural Livelihood (2001-2019)	% Decline in Rural Livelihood (2001-2019)
1000-1500	10	7775	1215	625	590	49.00
1500-2000	07	9715	1977	1050	927	47.00
2000-2500	18	14155	3555	2105	1450	41.00
Ramgad Watershed	35	31645	6747	3780	2967	46.00

Secondly, the food-grains is made available to the local people through (i) government controlled system, and (ii) open market system. The government system is known as Public Distribution System (PDS) through which essential food commodities, such as, wheat, wheat-flour, rice, sugar are made available to poor families (i.e., families below poverty line as categorized by the government) by the government controlled fair price shops in prescribed quantity at reasonable price. Whereas, the families above the poverty line can buy food commodities from other shops at open market rates, as per their requirements. Since, the majority of the families have very low level of income, PDS has played very significant role in ensuring food security in the region. However, during the recent years, the PDS has almost collapsed in the region as in many other parts of the country due to failure of government control over procurement and distribution of food commodities; and again, this is posing severe challenge in improving food security in the region in the era of climate change. Further, the procurements of food either from Public Distribution System (PDS) or from open market depends on the level of cash income and purchasing power of the people. In rural areas the community food purchasing capacity largely depends on the opportunities of livelihood in traditional rural sectors. But, as discussed in the preceding section the prospects of rural livelihood in these important conventional sectors have reduced considerably over the last 20

years mainly due to climate change and depletion of natural resource base and resultant decline in forest, agriculture and livestock productivity.

As in other parts of Himalaya, the remittance sent by the migrated population constitutes the principal source of income and food purchasing power of rural communities both from Public Distribution System (PDS) and open market in the region. But, it was observed that it would be difficult to fill the food deficit gap in near future as the local income level and purchasing power have declined due loss of employment opportunities to migrated population outside the region due to out-break of Covid-19. Although, the wider impact of Covid-19 on different sectors of economy are yet to be investigated, yet it is being widely accepted that this will definitely have long-lasting and severe impact both the access of food in all parts of country including the Himalayan mountains. It was investigated that the level remittance has decreased by 50-75% in different villages during March - April 2020 affecting the community food purchasing power in the region. Besides, the hike in the prices of food commodities during the recent years has also reduced the purchasing power of local people between 30-35% which has further aggravated the food insecurity situation in the region (Tiwari and Joshi, 2012b). Besides, the prices of essential food commodities, such as, wheat flour, rice and pulses have increased considerably during the last some years rendering these food items inaccessible to poor families undermining food and nutrition security of poor household in the Watershed.

Out of the total population (31645 persons) of Ramgad Watershed 16255 amounting to 51.47% have been identified as food insecure (Table 7). The largest proportion of food insecure population (53.27%) was found in the Middle Elevation Zone lying between 1500 and 2000 m from the mean sea level; followed by the Low Elevation Zone ranging from 1000 to 1500 m. Whereas the lowest percentage of food insecure population is in the Middle Elevation Zone situated between 1500 and 2000 m in the watershed (Table 7). Further, the proportion of food insecure population increased from 42.41% in 2001 to as much as 51.47% in 2019 thus registering an overall increase of 09.07%. This is mainly because of the massive loss of rural livelihood opportunities and consequent decline in community access to food across the region. The highest increase in food insecure population was observed in the Middle Elevation Zone situated between 1500 and 2000 m in the watershed where the food insecure population increased by more than 13% during the last 18 years (Table 7). The very high rise in food insecure population in the zone is explained by the fact that the area not only experienced sharp decline in water

availability for irrigation; but also recorded frequent crop failure due to flash floods, landslides and winter droughts during almost the last 2 decades. Moreover, the Middle Elevation Zone also registered abrupt decrease in employment opportunities in traditional sectors that restricted access to food of the majority of the population in the watershed during 2001 - 2019.

Table 7. Food Security Situation in Ramgad Watershed

Altitudinal Transact	Total Population				Food Insecure Population (% of Total Population)			
	2001	2019	% Increase (2001-2019)	Food Insecure Population (2001)	% Food Insecure Population (2001)	% Food Insecure Population (2019)	% Food Insecure Popul-ation (2019)	% Increase (2001-2019)
1000 - 1500	4559	7775	71.54	1945	42.66	3945	50.74	08.08
1500 - 2000	6456	9715	50.00	2557	39.60	5175	53.27	13.67
2000 - 2500	11070	14155	27.86	4977	44.96	7135	50.41	05.45
Ramgad Watershed	22085	31645	49.80	9479	42.41	16255	51.47	09.07

Marginal and small farmers, landless households which mainly include socially backward communities and families with marginal or very small income constitute the highly food insecure section of rural community in the region. The communities most vulnerable to food insecurity in the region mainly include marginal and small farmers with land holding size less than 1 ha (45%), landless households mainly include socially backward communities (5%), households with marginal income from other sources (41%), households with no income from other sources (9%), and households with most of the cultivated land rain-fed and with scarce family labour. The study revealed that most of the food insecure households in the region are not able to manage enough food for themselves, and in order to cope up with the

situation they have to reduce the consumption of a variety of essential but expensive food commodities, such as rice, pulses and sugar ranging from 30% to 45% in different villages. However, people are consuming locally grown pulses but these are low in productivity. This has had an adverse impact on the nutrition and health of a large proportion of the rural population in the area. This will have long-term impacts in food security of the region in terms of quantity, quality and nutritional value of the food affecting particularly the poor and socially marginalized people which constitute nearly 75% of the total population.

3.1.2 Conclusion and Way forward

The availability of and access to food is largely determined by community food purchasing power and infrastructural facilities for the supply and distribution of food in the region. The climate change, particularly the changing pattern of rainfall and increasing frequency and severity of extreme weather events have drastically reduced food production, decreased rural livelihood opportunities, and consequently increased the vulnerability of large proportion of population to food insecurity. The study clearly indicated that the steadily mounting food deficit and declining food purchasing capacity are likely to further undermine the food security of local communities in coming years. Besides, the continuing inflationary trend in the prices of food commodities may further reduce the access to food of local people. The long-term impacts of changing climatic conditions and increasing frequency and severity of climate change induced natural disasters would certainly change the conditions for food production in Himalaya through influencing the cropping pattern, crop rotation, cropping strength, and cropping intensity; and thus increase the vulnerability of local communities to food insecurity. This will have long-term impacts on food security of the region in terms of quantity as well as quality of food affecting particularly the poor and socially marginalized people which constitute nearly 75% of the total population.

Moreover, conventional adaptation practices and coping mechanisms to climate change and natural disasters are losing their efficiency, particularly in long-term perspectives, and emphasizing an urgent need for new response strategies to cope with these rapid and unprecedented changes. Nevertheless, practically agriculture will remain as one of the important economic activities in the entire Himalaya, and thus will constitute one of the core components of overall climate change adaptation strategy in the region in times to come. Firstly, the agriculture is not merely an important economic activity and fundamental source of livelihood of local rural

communities, but it also constitutes an integral part of their lifestyle, conventions, history and traditions, and a precious reservoir of local knowledge which are requisite for improving community adaptive and coping capacity to climate change and disaster risk reduction. Secondly, the Himalayan mountains have some of the highly productive and agriculturally prosperous valleys and mid-slopes which have still potential of contributing towards the food as well as livelihood security in the region. Thirdly, the potential of varying agro-climatic zones from valleys to higher elevation can be utilized for growing variety of crops and producing seasonal as well off-season agricultural products.

In view of this, capitalizing upon both the socio-cultural and biophysical strength of the mountain ecosystem agriculture has the potential to contribute significantly towards securing sustainable livelihood opportunities, particularly for the poor and marginalized mountain communities as well as an effective climate change adaptation and disaster management strategy. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification of agriculture, horticulture, floriculture, dairying, forestry, and for improving productivity of entire mountain crop and livestock system. In order to attain this, the mountain agriculture should be considered as one of the integral components of an overall, integrated development framework. The mountain agriculture therefore need to be integrated into ongoing poverty reduction programmes, food and livelihood improvement strategies, rural employment schemes as well as with ecological restoration and climate change adaptation and disaster risk reduction action plans in Himalaya. At the same time, small- scale structural as well biological water harvesting measures, for instance, rainwater harvesting, conservation ponds, and irrigation channels, drip water irrigation; and an early warning system for flash floods and droughts could also contribute towards improving food security enhancing the adaptive capacity of local communities to climate change. Further, integration of different sectors of Himalayan economy with local agricultural production system, flow of credit to rural areas, access to improved agricultural technology, increased investment in mountain agricultural enterprises, development of marketing and processing facilities and a strong institutional mechanism will not only help in making Himalayan agriculture a sustainable livelihood option but also create employment opportunities both in agricultural and non-agricultural sectors. This would help in reducing the vulnerability of mountain communities to food insecurity on the one hand, while on the other build climate change resilient mountain socio-ecological system through improved management

of land, water and forest resources. The situation underline the urgent need of creating viable means and opportunities of livelihood for rural communities in non-land based sectors, besides evolving effective framework for the development of climate smart and disaster resilient farming system based on the adaptive management of agricultural resources.

3.2 Climate Resilient Integrated Farming System for Improving Food Security in Himalaya under Climate Change

3.2.1 Observations and Inferences Drawn



Fertile Agricultural Land along Kosi River

As in other parts of Middle Himalaya, the traditional agricultural system in Upper Kosi Catchment is a highly diverse and interdependent covering all land based activities such as agriculture, horticulture, animal husbandry, and a variety of land, water, forest and biodiversity conservation practices owing to their organic and functional linkages (Everard et al., 2018). The farming system comprises a variety of cereals, legumes, tubers, fodder, fodder trees and livestock (Singh and Rao, 2001). It has been observed that the performance as well as the pattern of agriculture in the region is determined and shaped by a set of complex and interconnected specificities that include, inaccessibility, fragility, marginality, diversity, niche and human adaptation mechanism to these conditions (Jodha, 2005). These typical characteristics present a range of opportunities and constraints for agriculture in the Headwater, and also influence human responses to them (Jodha, 1997 and 2005). Diversity in agriculture is the product of interactions between various physical determinants and socio-cultural and economic elements. This influences the spatial structure of production processes and consumption pattern; results in limited scale-associated benefits; and requires territorial diagnosis followed by diversified interventions and

decentralized arrangements (technologies, infrastructure, and institutions) (Jodha, 1997 and 2005). This complex and integrated agricultural system not only contributed to environmental sustainability; but also to food, nutrition and livelihood security to a large segment of rural population in the region (Maithani, 1996). The variations in topographical features and climatic complexities along three dimensional mountain landscape from low lying valleys to higher elevations create diversity in agro-ecological system, resulting into a range of farming and food systems. In Himalaya, at lower mountains, intensive irrigated mixed farming systems are the most common form of agriculture; whereas, at higher elevations pastoralism with seasonal transhumance is the most common livelihood option as the rising altitude, decreasing temperature and steeper slopes limit the carrying capacity of natural resources (Huddleston and Ataman, 2003).

It was observed that farming communities in Kosi Headwater have developed a diverse, complex and sustainable farming systems for optimal production of food; and conservation of land, water and forest resources through generations (Tiwari et al., 2019: Pandey et al. 2017). The farming system integrates land, water, forest and livestock resources that makes it a complex, diversified and interdependent production system consisting of crop production, animal husbandry and conservation of land, water, forest and biodiversity resources (Tiwari and Joshi, 2012a, 2013, 2014 and 2018a). The farming system consists of four sub-systems: (i) forest; (ii) agriculture; (iii) livestock; and (iv) human population with organic inter-linkages with each other evolved under the diversity of terrain and complexity of climatic phenomena and sustained with organic matter and nutrients originated from the forests and rangelands (Pandey et al., 2017). The traditional agricultural system has contributed significantly not only towards preserving the diversity of high value genetic resources of plants and animals; but also ensured food, livelihood and nutrition security to local communities since time immemorial (Ramakrishnan, 199). The system is vast repository of a large variety of crops and cultivars adapted to diverse natural as well as socio-cultural traits of the region; and contributed significantly towards maintaining the diverse farming systems, farming situations, cropping systems, crop diversity and genetic variability within species (Bahera et al., 2004; Yadav et al., 2013).

The mixed cropping pattern is one the unique characteristics of the traditional farming system in the entire region which consists of five categories of crops: (i) cereals; (ii) millets; (iii) pulses; (iv) vegetables; and (v) oil seeds. This system not only helps in maintaining high crop genetic diversity under low carrying capacity of

natural resources; but also ensures optimal production for food and nutrition security under severe geo- environmental constraints (Bose, 2018). The enormous diversity of cultivated and wild plants, providing a variety of edible products in diverse geo-environmental conditions is one of the most important features of local traditional farming system (Pande et al., 2016). The system consisting of massive diversity of cultivated and wild plants provides food, nutrition and livelihood security to local communities; maintains the diversity and stability of traditional mountain farming system; and preserved landscape diversity and natural resources (Choudhary, 2013). As in other parts of Himalaya, the rural communities in the region have developed a variety of indigenous farming techniques for optimal production under low carrying capacity of natural resources. Such production systems are the reservoirs of a huge variety of food and cash crops and cultivars.

Figure 7 presents a broad land use pattern of Kosi Headwater. Out of the total land surface area of Kosi headwater (107.94 Km^2) 77.00 Km^2 or nearly 71.00% is under forest of which as much as 68.22% comes under reserve forests (State Owned Forest) and only 3.11% has been included in the category of community forests that mainly includes civil forests, panchayat forests (Forest Councils) and village forests managed under Joint Forest Management (JFM). More than 27.76 Km^2 areas amounting to 25.72% of total area of the watershed is under agriculture (Table 8 and Figure 7). The catchment of Kosi constitutes one of the heavily populated, densely cultivated and highly productive valleys of Kumaon Himalaya (Joshi et al., 1983). Out of the total cultivated land (27.76 Km^2) only about 15% is irrigated, and the rest of the cultivated land, mainly lying at higher elevations, is very sparsely irrigated primarily due to the non-availability of adequate amount of water and its improper management. However, the rain-fed slope support a large population by providing habitats for a large variety of food as well as horticultural crops and constitute source of springs and streams that sustain irrigated farming in the down-streams.

The agricultural land in the region is spatially distributed along the altitudinal transact ranging from below 1400 m to 2200 m from the mean sea level, and in general the cultivated land increases with the increase in altitude up to an elevation of 2000 m. The maximum concentration of cultivated land (43.25%) has been observed in altitude ranging between 1500 and 2000 followed by 2000 - 2200 (27.43%). However, the agricultural land at lower elevation of below 1500 m is merely 12.66% as the hill slopes below 1500 m altitude are characterized by dissected slopes, and the availability of cultivated land is only confined to river

terraces, colluvial fans and cones of with gentle slope. As much as 75% of the irrigated land is confined up to 1800 m in the region. The most favorable sites for cultivation are wide valley floors mainly characterized by alluvium rich terraces and gentle fans and gentle slopes with moderate elevation. Table 8 showing village-wise distribution of cultivated land in Kosi Headwater makes it clear that as many as 47% villages of the region have been cultivated very intensively with as much as 75% of their total geographical land surface under agricultural production system. These villages with intensive cultivation are situated along the low-lying valleys, particularly on the river terraces and fertile fans. Out of the total villages 15 have cultivated land ranging from 45 to 75% of their total land surface. Only three villages of the watershed have less than 45% of their total geographical area under cultivation (Table 8).

Table 8. Village Wise Distribution of Cultivated land in Kosi Headwater (2019)

% of Cultivated Land to Total Village Area	Number of Villages	% of Total Area
Below 15	01	1.54
15 – 30	01	1.54
30 – 45	01	1.54
45 – 60	04	6.15
60 – 75	11	16.92
Above 75	47	72.31
Total	**65**	**100.00**

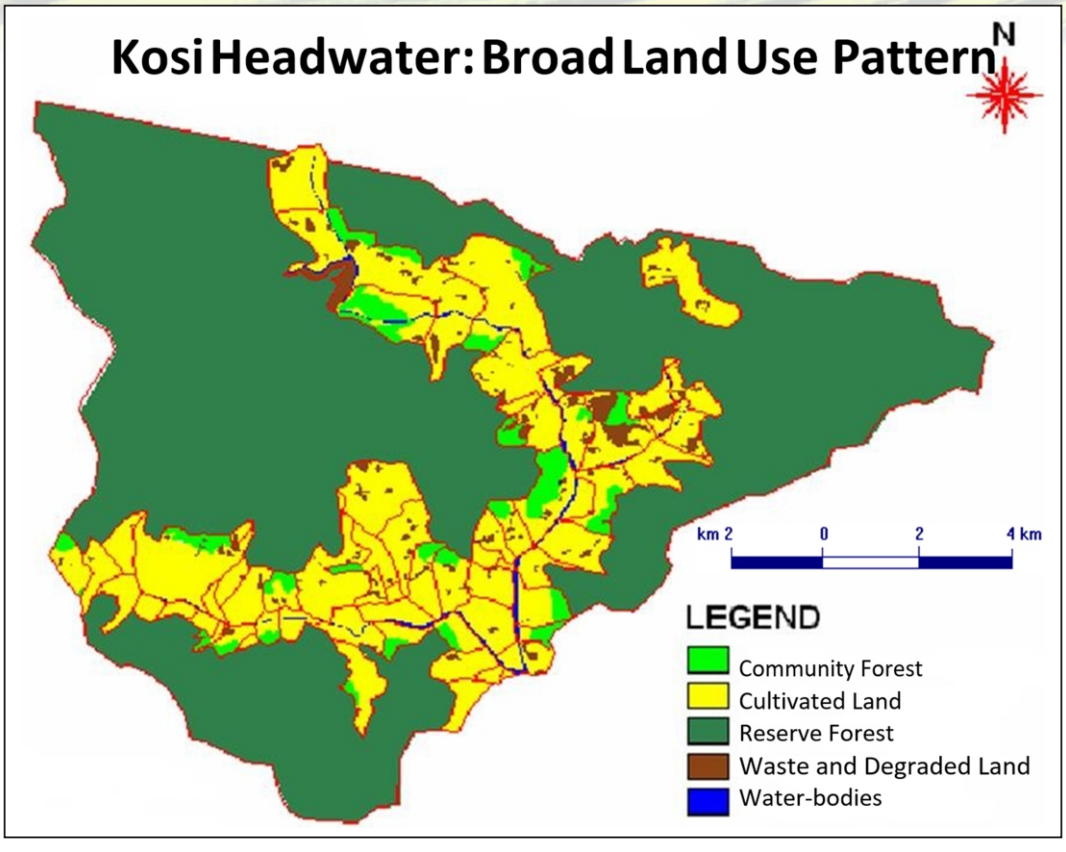


Figure 7. Broad Land Use Pattern in Kosi Haedwater

As mentioned earlier, the headwater of Kosi river is one of the most heavily populated and agriculturally highly fertile valleys of Kumaon. The Watershed has registered very high growth of population during the past some decades, as a result the density of population is also very high. The density of population ranges between 100 person/km^2 to as high as 1100 person/km^2 (Table 9). The villages located along the fertile river terraces along the river are very heavily populated with very population density (Figure 8). This is brought out by the fact that the availability of cultivated land has declined considerably during years 1991 and 2019. Table 10 shows that in the year 2019, out of the total villages, 22 and 9 had per capita cultivated land respectively ranging between 0.05 and 0.10 ha and 0.10 - 0.15 ha, whereas, only 3 villages of the region had per capita cultivated land above 0.15 ha. Table 10 which also summarizes the availability of per capita arable land in 1991 shows that the man-land-ratio has declined steadily and significantly during the last

30 years in the watershed. In 1991 there were 5 villages in the watershed having per capita cultivated land more than 0.15 ha against only 3 villages in 2019. Similarly, the number of villages has reduced from 11 to 9 in the category of 0.10 - 0.15 ha/person between 1991 and 2019 (Table 10 and Figure 9). But, the number of rural settlements with low per capita cultivated has increased in the watershed during the same period (Table 10). The main factor for this continuously declining man-land-ratio in the headwater is that despite the extension of cultivation and increasing trends of rural out-migration the horizontal development of agriculture has not been able to keep pace with the growth of population in the region. The study of operational land holdings size revealed that more than 98% land holdings in the watershed are of below 1 ha, and there is not a single village in the entire area with land holding of above 5 ha.

Table 9. Village Wise Distribution and Density of Population in Kosi Headwater

Population Size and Density Groups (Persons/km^2)	Population Size		Population Density	
	Number of Villages	Percent of Total Villages	Number of Villages	Percent of Total Villages
Below 200	28	43.08	11	16.92
200 – 400	15	23.08	20	30.77
400 – 600	08	12.31	15	23.08
600 – 800	05	07.69	08	12.31
800 – 1000	07	10.77	06	09.23
Above 1000	02	03.07	05	07.69
Total	**65**	**100.00**	**65**	**100.00**

Table 10. Per Capita Cultivated Land in Kosi Headwater

Per Capita Cultivated Land in ha	1991		2019	
	Number of Villages	Percent of Total Villages	Number of Villages	Percent of Total Villages
Below 0.05	21	32.31	31	47.69
0.05 – 0.10	28	43.08	22	33.85
0.10 – 0.15	11	16.92	09	13.85
Above 0.15	05	07.69	03	04.61
Total	**65**	**100.00**	**65**	**100.00**

Indigenous farming system of the region is quite scientific, stable and sustainable. Traditional farming practices involve the cultivation of multiple crops in a small terraced field which helps in ensuring food and nutrition security, preserving agro-biodiversity, maintaining soil fertility and in coping with climate change and natural disasters (Roy and Kumar, 2018). As many as seventeen local varieties of crops are being cultivated in the region; and this huge crop-diversity has been maintained through a variety of crop compositions, cropping patterns and crop rotations (Singh and Rao, 2001). These seventeen agricultural crops were grouped into five categories: (i) cereals (paddy, wheat and barley); (ii) millet and pseudo-millet (amaranths, buckwheat, finger-millet and maize); (iii) pulse (black-bean, French-bean, horse-bean, soya-bean, green gram and pea); (iv) vegetable (potato); and (v) oil seed (mustard). Out of the total seventeen food and cash crops, twelve crops are grown in mixed in up-slopes during monsoon season (June - September); and three crops namely wheat, barley and mustard are cultivated in winter season (October-May). Normally, wheat is grown with mustard; and pulses are cultivated in twelve different crop compositions intermixed with millets and pseudo- millets. The number of crops constituting the combination ranged from 2 to 5 (Singh and Rao, 2001).

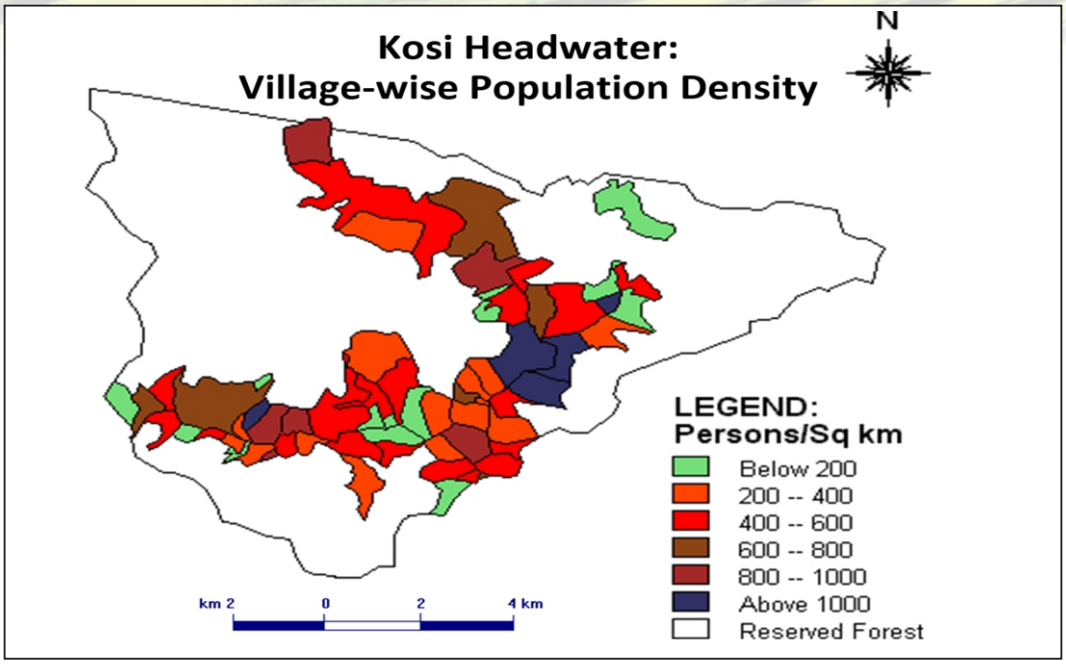


Figure 8. Village-wise Population Density at Kosi Headwater

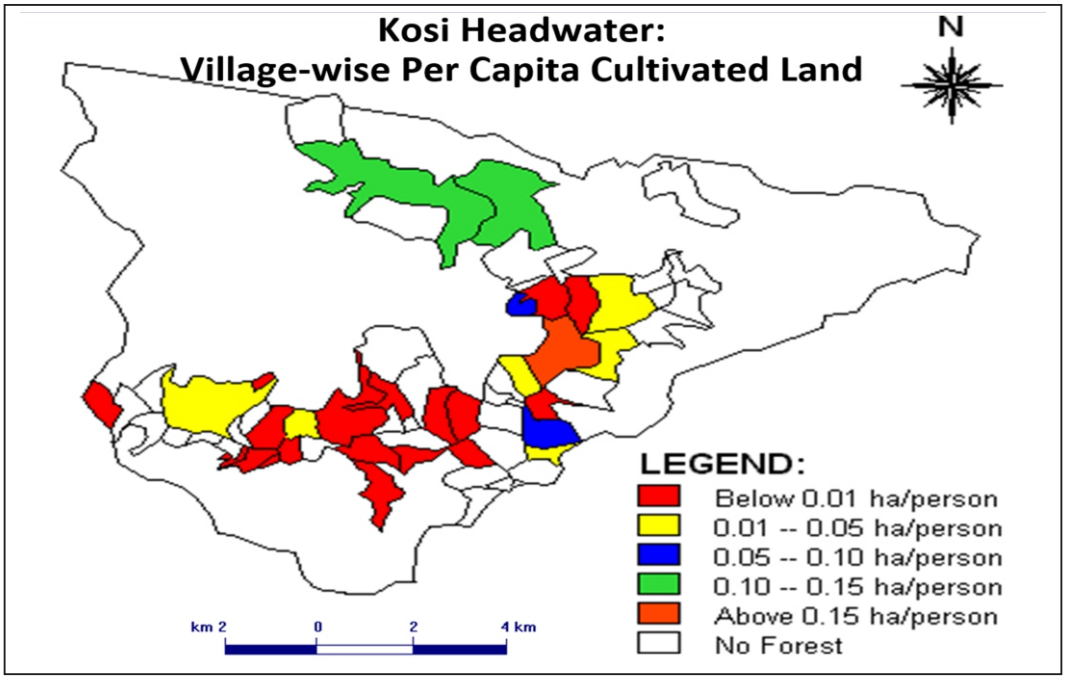


Figure 9. Village-wise Per Capita Cultivated Land at Kosi Headwater

Emerging Threats to Traditional Farming System

It was investigated that as in other parts of Himalaya the conventional farming system is now collapsing due to various natural and socio-economic factors in Kosi Headwater. The study brought out the fact that a range of drivers particularly rapid urbanization, mounting human-wildlife conflicts, increasing trends of rural outmigration, climate change and climate change induced natural disasters have transformed the traditional agricultural resource use structure in the region over the past 25-30 years (Tiwari and Joshi, 2008 and 2012b). As a result, land use pattern has changed and critical natural resources, such as, land, forest, water, and biodiversity have depleted steadily and significantly declining agricultural production and increasing vulnerability of large population, particularly poor and marginalized population to food, nutrition and livelihood insecurity (Tiwari, 2000; Tiwari et al., 2018). The intensification of land use on fragile mountain slopes and resultant depletion of forest resources have disrupted ecosystem services, eroded biodiversity, decreased availability of fodder to livestock and reduced supply of biomass compost manure to agriculture (Tiwari et al., 2017). It was observed that the loss of important environmental services, particularly the decline in the productivity of forest biomass due to depletion and degradation of forest ecosystem has adversely affected the farm productivity in the entire watershed. The interpretation of primary data collected through household surveys revealed that the supply of manure to agricultural land has declined from15 tonnes/ha/year in 1980 to 6 tonnes/ha/year in 2019 with an overall decrease of about 6 tonnes/ha/year (40%). The declines in the productivity and availability of fodder have decreased livestock productivity which is further undermining the food and nutrition security in the region (Tiwari and Joshi, 2012b).

The increasing trend of the abandonment of agricultural land has emerged as one of the serious threats to farming system, particularly in Western Himalaya. The Himalayan State of Uttarakhand has lost 10.32% of its agricultural land during 2001 and 2015 due to increasing trends



Abandoned Agricultural Land along Kosi River due to Flash Flood and Drought

rural- outmigration and resultant abandonment of farmland (Anmol, 2011; Tiwari, and Joshi, 2018a; Joshi, 2018). The depletion of natural resources and resultant decline of agronomic production; climate change and frequent crop-failures caused by increasing incidences of weather extremes were identified as the main drivers of rural-outmigration and agricultural abandonment in Himalaya (Mamgain and Reddy, 2017). Moreover, during recent years, incidences of human and livestock killings and crop depredation increased due to steadily growing wildlife population resulting into serious human-wildlife conflicts and abandonment of agricultural land. The increasing human-wildlife conflicts contributed 75% land abandonment causing loss of more than 1500 human-lives,1100 livestock and devastation of nearly 60% crops in Himachal Pradesh and Uttarakhand during the last 10 years (Kansky and Knight, 2014).

Himalaya is the most rapidly urbanizing mountains of the world, but the process of urban growth is mostly unplanned and unsystematic leading to extension of urban land use in peri-urban areas (Tiwari et al., 2018). The Western Himalayan States of Himachal Pradesh and Uttarakhand respectively lost 4.71% and as much as 12.97% of their prime agricultural land due to urban encroachment during last 30 years causing huge decline in agricultural productivity (Tiwari and Joshi, 2011 and 2016; Tiwari et al., 2018). Besides, the introduction of High Yielding Varieties (HYV) of food and cash crops particularly wheat, paddy and potatoes; and resultant application of modern farming inputs, specifically, chemical fertilizers, pesticides and insecticides and market influences have eroded values and knowledge of integrated farming system during the recent years (Rasul et al., 2019; Singh and Rao, 2001). This transformation of mountain agriculture has resulted into massive loss of mountain agro-biodiversity, depletion of natural resources and genetic diversity, erosion of valuable traditional knowledge, and disintegration of farming system in the region (Tiwari et al., 2019).



Rain-fed Agricultural Terraces in Kosi Valley

The study indicated that climate change, particularly the increasing variability in

rainfall pattern has further stressed the traditional agricultural economy through disruption of water cycle, increasing occurrence and severity of climatic extremes. It has been investigated that during the last 30 years the quantity of annual rainfall as well as the number of annual rainy days declined respectively by 15% and 25% in the watershed. Consequently, the availability of water resources for both domestic uses and crop production has decline considerably in the entire region Moreover, a large number of small streams amounting to 736 m have dried over the past 3 decades in the area. Nearly 73 (37%) of natural springs have gone dry and 28 (14%) have become seasonal, primarily due to the decreasing trend in rainfall and declining groundwater recharge in the Headwater. These hydrological disruptions are very clearly visible in the terms of: (i) steady decline in stream and spring discharge, (ii) drying of natural springs; and (iii) altered run-off process and channel network capacities (Rawat, 2009, Valdiya et al., 1991, Tiwari and Joshi, 2012a). In turn, these have adversely affected irrigation potential, which has declined significantly over the past 30 years, mainly owing to above-mentioned hydrological disruptions and resultant reduction in groundwater recharge in the region (Rawat et al., 2020). A total of 38 villages are water scarce and there has been a decline in irrigated area of 78 ha (16%) The decrease in irrigated area ranged between 3 ha and 40 ha (14% and 21% of total irrigated land) in different villages. The increasing occurrence of hydrological droughts and incidences of heavy to very heavy rainfall increased respectively 10% and 14% resulting into frequent flash floods, landslides and slope failures. Consequently, agricultural productivity declined (25%) leading to 65% food deficit undermining food security of 75% population mainly consisting of poor and marginalized sections of rural population. Furthermore, rural livelihood opportunities in agriculture and livestock sectors have declined respectively by 24% and 15% reducing community food purchasing capacity (Tiwari and Joshi, 2012b).



Abandoned Agricultural Terraces in Kosi Valley

Long-term impacts of changing climatic conditions are likely to cause enormous decline in food productivity, and consequently increase the vulnerability of large population, particularly poor and marginalized groups of rural society to food insecurity. The impact of climatic variability is particularly severe in rain-fed agricultural system where balance between the availability and demand exists at a very low level with a high vulnerability (Heath et al., 2018). As a result, the productivity of agriculture has declined by nearly 125 Kg/ha (25%) between 1980 and 2019, and per capita food productivity has decreased from 190 Kg to 120 Kg per annum during the period. As a result, in 2019 the different villages in the catchment faced a food deficit ranging between 174 tonnes/year (76%) and 881 tonnes/year (79%) with an overall food shortage of 1883 tonnes/ha (65%). It is expected that production of food is likely to decline further mainly due to increasing water-stress arising partly from rising temperature and reduction in number of rainy days creating a very high risk of food insecurity (Tiwari and Joshi, 2012a and 2012b; Department of Science and Technology, 2010). The long-term impacts of changing climatic conditions would certainly change the conditions for food production in the region through influencing the cropping pattern, crop rotation, cropping strength, and cropping intensity, and thus increase the vulnerability of local communities to food insecurity (World Bank, 2018; Cline, 2008).

Development Climate Resilient Integrated Farming System in Himalaya

As discussed in the preceding sections, more than 75% population of the region depends on traditional agriculture for its livelihood and supply of food although the proportion of cultivated land is sternly limited and crop-productivity level is remarkably very low (Tiwari and Joshi, 2012b; Anmol, 2011). Nevertheless, practically agriculture will remain 54

as one of the important economic activities in entire Himalaya; and thus will not only constitute main source of food and livelihood; but also comprise one of the core components of overall development and climate change adaptation strategies in the region in times to come (Jodha, 2005; Tiwari and Joshi, 2018a). This is firstly, because the agriculture is not merely an important economic activity and constitutes fundamental source of livelihood and food for local rural communities; but it also constitutes an invaluable treasure of traditional ecological knowledge and sustainable resource management practices that need to be incorporated in climate change adaptation and disaster risk reduction plans at local level (Jodha, 2005).

Secondly, Himalaya has some of the highly productive and agriculturally prosperous valleys and mid-slopes with wide agro-climatic diversity and large potential of contributing towards the food as well as livelihood security to mountain communities under changing climatic conditions. Thirdly, the potential of varying agro-climatic zones from valleys to higher elevation can be utilized for climate change and natural disaster resilient integrated farming system comprising of agriculture, horticulture, floriculture, dairying, and forestry through adopting a combination of traditional as well as appropriate modern farming techniques and technologies. Fourthly, all sustainable development strategies aiming to attain food and livelihood security and environmental sustainability under climate change need to be linked with local agricultural and food systems through value-chain development at local level in the Headwater as well as in other parts of Himalaya (Scott et al., 2019). Lastly, integration of different sectors of Himalayan economy with local agricultural production system will create local viable market for the agricultural products; and thus make local agriculture economically viable and resilient to climate change and natural disasters (Campbell, 2008).

However, this requires evolving an integrated climate change adaptation framework with climate resilient agriculture as one of its integral components. The climate change adaptation is 'adjustments in human and natural systems in response to actual or expected impacts of changing climatic conditions and climate change induced natural disasters, with a view to moderating harm or exploiting beneficial opportunities' (IPCC, 2014). Further, climate change adaptation is 'the process of adjustment to actual or expected climate and its effects' (IPCC, 2014). Adapting to climate change involves taking the appropriate and effective measures to reduce the adverse impacts of climate change and make use of the positive ones by making the timely and proper adjustments and changes in the natural, social, economic, cultural and political systems. In view of this, there are several options and opportunities to adapt Himalayan farming system to climate change depending upon the level of vulnerability and capacity of the system to respond to climate change.

The Climate Resilient agriculture is one of the integral component of overall climate change adaptation strategy in agricultural sector. Climate Resilient Agriculture can be defined as ‘agriculture that reduces poverty and hunger in the face of climate change, and contributes towards strengthening the natural resources base.’ (CORDAID, 2016).

Climate Resilient Agriculture aims to transform the current agricultural systems, and has a wider perspective than increasing only food productivity. It supports food production systems that are socially acceptable, economically viable and environmentally sustainable (FAO, 2018). This clearly indicates that climate resilient agriculture provides a comprehensive, integrated and ecosystem based approach for the sustainable development of natural resources for increasing food and livelihood security under climate change. In view of this, the climate resilient farming is more conducive to mountain regions where the agricultural production and community livelihood mostly depends of inter-dependent natural systems.

In view of this, the integrated farming system that facilitate the sustainable utilization of land, water, forest and biodiversity resources for attaining optimal production level from various farming as well as non-framing enterprises has the potential to be developed as climate resilient agricultural system for Himalaya (Tiwari et al., 2019; ICIMOD, 2018). In order to harness the potential of integrated farming system, we need to evolve effective strategies to enhance the carrying capacity of agricultural resources including social and economic assets to ensure high productivity level without degrading the ecosystem and depleting natural resources base (ICIMOD, 2018; FAO, 2008). Since the climate change resilient agriculture emphasizes the sustainable development and utilization of natural resources, particularly, land, water, forests and biodiversity; this should constitute one of the integral components of overall agricultural adaptation process not only in Himalaya, but also in high mountains of the developing countries and less developed countries (FAO, 2019 FAO, 2018b).

Further, this underlines the need of integrating agricultural adaptation strategy into the overall process of natural resource development that involves efficient utilization of natural, human, financial and technical resources particularly at local levels (FAO, 2018). In view of this, in Himalaya, it is being urgently realized that the climate change adaptation programmes needs to be integrated into a cross-cutting and inter-sectoral development process through its mainstreaming into overall local development planning (Tiwari et al., 2019). As discussed in the preceding section, agriculture is going to be one of the important components of sustainable development framework and climate change adaptation strategy in Himalaya. It is therefore highly imperative that climate resilient agriculture should constitute one of the core elements of the overall natural resource development process and climate change adaptation strategy in the Himalayan mountains. Since, the mountain agriculture relies on the utilization of land, water, forests and biodiversity resources

which are inter-dependent in nature; watershed provides the most ideal natural unit for the development of climate resilient framing system and its mainstreaming with integrated natural resource development programmes. This is mainly because watershed in an natural, hydrological and resource unit (World Bank, 2016; UN, 2012); a socio-political-ecological entity which plays vital role in providing a variety of ecosystem services to population living both in up-streams and down-streams (FAO, 2008); and a geographical region that integrate land and water resources (Haigh, 2002; World Bank, 2016).

In view of this, an attempt has been made in the present study to evolve a climate resilient integrated farming system, and integrate it into integrated watershed management programmes involving local government departments, village institutions and local communities. In view of this, an integrated farming system development plan was formulated for each of the 65 villages of Kosi Headwater with focus on: (i) promoting crop diversification; (ii) increasing agricultural productivity; (iii) enhancing rural livelihood and income generating opportunities; (iv) improving food security; (v) sustainable development of land, soil, water, forest and biodiversity resources; and (iv) enhancing community capacity to adapt to climate change and climate change induced natural disasters.

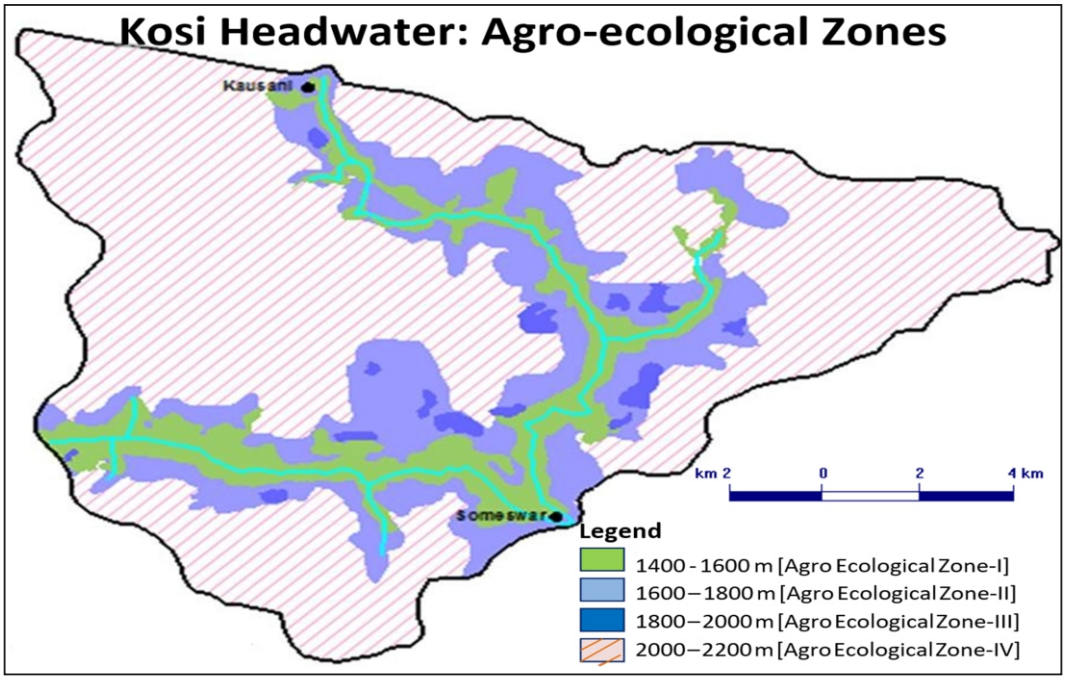


Figure 10. Agro-ecological Zones at Kosi Headwater

The development of integrated climate change resilient farming system for Kosi Headwater involved the following exercises:

- The entire watershed was divided up into 4 Agro Ecological Zones primarily based on altitude, slope, slope-aspect, temperature, precipitation, availability of water and broad soils characteristics using Geographic Information System (GIS). The 4 Agro Ecological Zones are: (i) Lowland River Terraces extending between 1400 m and 1600 m elevation from the mean sea level; (ii) Middle Slopes ranging from 1600 m to 1800 m; (iii) Upper Middle Slopes with elevation between 1800 m and 2000 m; (iv) Upper Slopes with an altitudinal range from 2000 m and 2200 m from the mean sea level (Figure 10).

- Land capability analysis was carried out for each of the agro ecological zones based on the interpretation of the parameters of surface slope and the soil depth and various socio-economic parameters determining the agricultural and food system in the region. Both the parameters taken into consideration for the land capability classification have been analyzed in Geographic Information System environment; and the average slope was considered as basic landscape parameter analyzing the land capability.

- An integrated farming system was evolved for all the villages located in each of the Agro Ecological Zones based on land capability, agricultural developmental and food security priorities of villages, availability of natural resources, such as, land, water and forests; transport connectivity; climate change adaptation and disaster risk reduction priorities; and options of the community and other stakeholders including local level government agencies and community based institutions. In order to evolve this framework and ensure it social and administrative feasibility, the boundaries of Agro Ecological Zones have been adjusted with village-boundaries in several cases.

- In order to ensure the environmental sustainability of the proposed farming system specific provisions have been made for the conservation and adaptive management of land, water, forest and biodiversity resources; and management of climate change induced disasters, particularly, droughts and landslides disaster risk reduction in each of the 4 Agro Ecological Zones. In view of this, participatory land, water and forest management, disaster risk reduction, gender mainstreaming, strengthening and application of local

traditional knowledge in climate change adaptation have been included as the common-core components of integrated farming system in all the 65 villages of the headwater in agreement with local level government agencies and community institutions.

- A combination of various agricultural crops that include paddy, wheat, barley, millets, pulses, oil seeds; livestock for milk and manure production; horticultural cash crops including potatoes, a variety of vegetables and fruits; cultivation of medicinal plants; and household level fish farming was proposed for each of the 4 Agro Ecological Zones. The proposed integrated farming framework has been evolved based on the observations that both varieties of crops and breeds of livestock with high stress tolerance have more stable and higher productivity under climate change and climatic extremes (Sati, 2016; FAO, 2019a and 2019b; 2007; Yadav et al., 2013).

Agro Ecological Zonation

The detailed description proposed agro-climatic zones and suggested cropping pattern is presented and summarized in Table 11 and Figure 115:

Agro Ecological Zone-I: extends along the Low-lying River Terraces encompassing a geographical area of 03.55 Km^2 in 5 villages of Kosi headwater between 1400 m and 1600 m elevation from the mean sea level. This Zone is characterized very gentle slope (020 - 150), thick alluvial soils and year round availability of water for irrigation. This is traditionally intensively cultivated area with high level of farm productivity. This Zone was found highly suitable for irrigated food and cash crop. The cropping pattern proposed for Agro Ecological Zone-I includes Agriculture (Paddy, Wheat, Potato, Pulses, Oilseeds); Horticulture (Potato); Milk Production and Fish Farming. Although this Agro- climatic Zone is the smallest in term of area as well as number of villages covered, yet the farm productivity is the highest compared to all other Agro Ecological Zones. The conservation of water and biodiversity resources, and drought management would be the important components of the integrated farming system proposed for the zone (Table 11 and Figure 11).

Agro Ecological Zone-II: is located in moderately sloping (150-200) Middle Slopes and covers an area of 11.77 Km^2 in 11 villages from 1600 m to 1800 m elevation. This area has low water availability, and affected by moderate soil erosion. The integrated farming framework evolved for the zone involves: production of a variety

of crops under: Agriculture (Wheat, Barley, Millets, Pulses, Oilseeds); Horticulture (Tea Farming, Potato, Green Vegetables, Pea, Cabbage); Milk Production and Fish Farming. Along with production of variety of food and cash crops, this Zone would focus on the conservation of water and biodiversity resources; and drought management (Table 11 and Figure 11).

Agro Ecological Zone-III: is situated in Upper Middle Slopes of the watershed between 1800 m and 2000 m altitude, and characterized by moderate to steep slope (200-350), high rate of erosion, low to very low availability of water and slope failures and mass movement. This is the largest Agro Ecological Zone both in terms of area and number of villages covered. This Agro-climatic Zone is constituted by 30 villages covering a geographical land surface of 12.57 Km^2. The crop-combination recommended for this Agro Ecological Zone includes: Agriculture (Wheat, Barley, Millets, Pulses); horticulture (Apricot, Plum, Peach, Pears); Milk Production; and Cultivation of Medicinal Plants. The proposed integrated farming framework would also integrate the water and biodiversity conservation and management winter and spring droughts. Besides, landslide risk and drought management; conservation of soil, water and forest resources should be given high priority while implementing the proposed farming system in the region (Table 11 and Figure 11).

Table 11. Proposed Agro-ecological Zones and Integrated Farming System

Agro-Climatic Zone	Altitude [Meters]	Villages	Area [Km^2]	Proposed Integrated Farming System	Priority Resource Conservation and Adaptation Options
Agro-ecological Zone-I: Lowland River Terraces	1400-1600	05	03.55	Agriculture [Paddy, Wheat, Potato, Pulses, Oilseeds], Horticulture [Potato], Milk Production, Fish Farming	Water Conservation, Biodiversity Conservation, Drought Management

Agro-ecological Zone-II: Middle Slopes	1600-1800	21	11.77	Agriculture [Wheat, Barley, Millets, Pulses, Oilseeds], Horticulture [Tea Farming, Potato, Green Vegetables, Pea, Cabbage], Milk Production, Fish Farming	Water Conservation, Biodiversity Conservation, Drought Management
Agro-ecological Zone-III: Upper-Middle-slopes	1800-2000	30	12.57	Agriculture [Wheat, Barley, Millets, Pulses], Milk Production, Medicinal Plants Cultivation, Horticulture [Apricot, Plum, Peach, Pears]	Landslide Risk Management, Soil and Water Conservation, Drought Management
Agro-ecological Zone-IV: Upper Slopes	2000-2200	09	07.11	Agriculture [Millets, Pulses], Milk Medicinal Plants Cultivation, Horticulture [Apple, Apricot, Plum, Peach, Pears]	Landslide Risk Management, Production, Soil and Water Conservation, Drought Management

Agro Ecological Zone-IV: is located in Upper Slopes of the watershed from 2000 m to 2200 m that determine the maximum altitudinal limit of the crop production in the region. The zone extends over 9 villages cover an area of 7.11 Km^2. The entire area is marked with steep surface slope (350-600), low average annual temperature, very thin and erosion prone soils, water scarcity for crop production and active landslides. The proposed cropping pattern suggested for this Zone include: Agriculture (Millets, Pulses); Horticulture (Apple, Apricot, Plum, Peach, Pears); Milk

Production and Cultivation of Medicinal Plants. As suggested for Agro Ecological Zone-III, top priority should be given to the community based management of landslide and drought and sustainable management of soil, water and forest resources as this entire area constitutes the source region of a large number of streams and springs which contribute to water availability is down-slopes (Table 11 and Figure 11).

It is expected that the proposed integrated climate change resilient framing system may go long way in improving the food and livelihood security, and adaptive and sustainable management of natural resources under climate change in the watershed which is highly vulnerable both to Climate Change and climate change induced natural disasters. However, in order to make the proposed integrated climate change resilient framing system an effective and community oriented climate change adaptation strategy, it should be supported by the development of comprehensive agricultural resources information system at watershed level; and development of value chain system

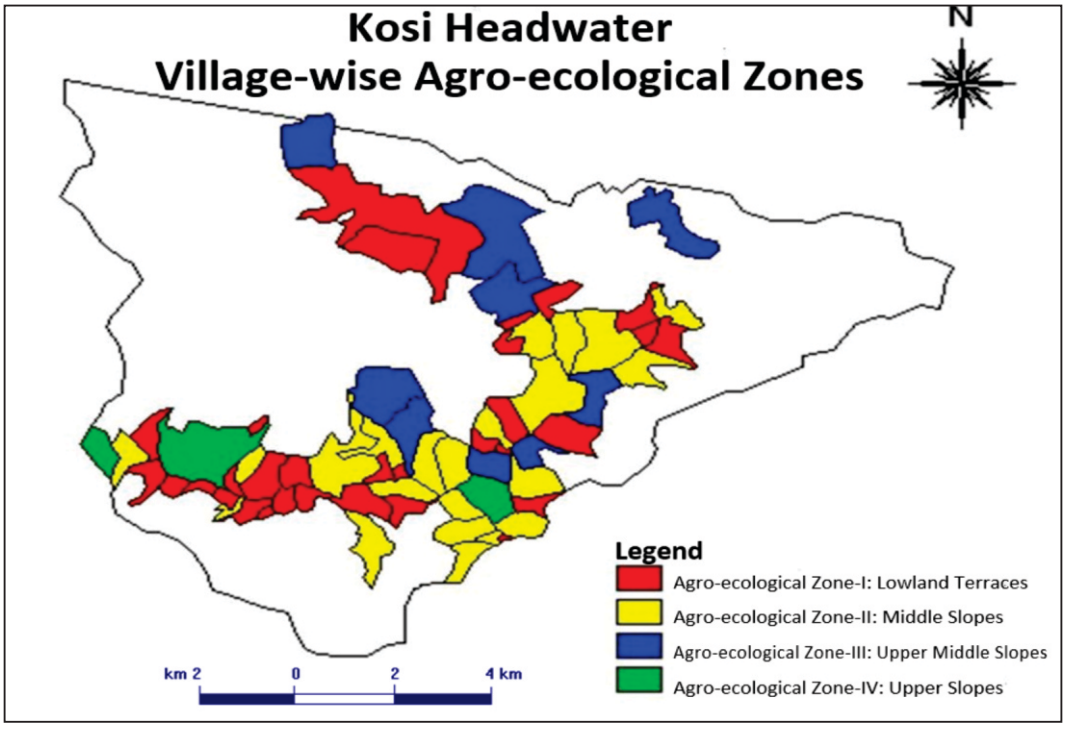


Figure 11.Village Wise Agro-Ecological Zones at Kosi-Headwater

Moreover, the improvement of marketing facilities based on locational planning of agricultural facilities and services would be necessary. Further, the integrated farming system should be linked with other sectors of mountain economy, particularly home-stay tourism and economic policies, such as, investment in mountain agriculture and comprehensive crop insurance. Moreover, climate resilient agriculture initiatives need to be sustained, increased and improved continuously incorporating the most recent knowledge, new experiences, and the best practices, to face the current challenges of food insecurity, resources depletion in face of climate change and natural disasters.

3.2.2 Conclusion

The experiences from other parts of the world indicate that integrated farming system contributes significantly towards sustainable food production and improving food security in disaster-prone areas, made traditional agriculture more resilient to climate change and helped in the restoration of depleting natural resources. Himalaya provides one of the best examples of integrated mountain farming system evolved through thousands of years of experimentation with fragility, inaccessibility and marginality and resultant low carrying capacity of natural resources. However, during the recent past the values of traditional farming system have eroded considerably mainly due to population growth, rapid urbanization, depletion of natural resource base, economic globalization and market influences and climate change. However, capitalizing upon both the socio-cultural and biophysical strength of the mountain landscape integrated farming system has the potential to contribute significantly towards attaining food and nutrition security as well as securing viable livelihood opportunities for mountain communities under climate change. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification and integration of agriculture, horticulture, floriculture, dairying, fishing, bee-keeping and forestry at watershed level.

In view of this, the proposed integrated farming system could be extended to the rest of Himalayan region and also to other high mountains in the developing and less developed world. However, in order to attain this, the mountain regions should adopt integrated watershed management approach, and climate resilient farming system should be an integral components of integrated watershed development programme. Further, the mountain agriculture needs to be integrated with ongoing various poverty eradication programmes, food and livelihood improvement

strategies, women's empowerment and gender mainstreaming schemes; and rural employment schemes as well as with ecological restoration and climate change adaptation mechanism. Moreover, integration of different sectors of mountain economy with local agricultural production system, flow of credit to rural areas, and increased investment on mountain agricultural enterprises will help in making mountain agriculture economically viable, ecologically conducive, and adaptive to climate change and natural disasters. This would require connecting disciplines, and thus promote coherence, consistency between agricultural and climate change adaptation policies, research, financial investments and sustainable development programmes. A multi-stakeholder governance framework involving government agencies, community organizations, CSO's, NGO's, private sector, research centres, funding agencies would be essential to further promote climate resilient agriculture in mountains. This would help different stakeholders contributing towards attaining the Sustainable Development Goals (SDGs) particularly SDG 2 (food security); and SDG 13; SDG 1 (poverty reduction), SDG 11 (resilient communities) and SDG 15 (protect ecosystems). Furthermore, continuing efforts in Climate Resilient Agriculture contribute to the implementation of the UNISDR Sendai Framework for Disaster Risk Reduction, and the UNFCCC Paris Agreement.

Chapter - 4
Strategic Recommendations

4.1 Technical Findings

- The study successfully demonstrated the application of Remote Sensing [RS] and Geographic Information System [GIS] in the delineation of agro-climatic zones and development of climate change and natural disaster resilient integrated farming system in high mountain terrain, such as the Lesser Himalaya.
- This clearly indicate that the emerging areas of science and technology, particularly Remote Sensing [RS], Geographic Information System [GIS], Global Positioning System, and other advanced scientific mapping system have enormous application potentials in climate change adaptation particularly in adaptive and integrated management of agricultural resources, specifically in high mountain regions.
- The study evinces that these technologies could be successfully used for the development of Disaster Risk Information System [DRIS] that would not only help in evolving and implementing effective disaster risk reduction framework, but also assist in developing quick response system at local level in mountain areas.

4.2 Methodological lessons/ innovations

- The study also provides a comprehensive methodological framework for integrating disaster risk reduction into climate change adaptation as the rapidly changing climatic conditions have increased the frequency, intensity and severity of natural disasters, particularly in the Himalayan mountains, and it is therefore highly imperative to integrate climate change and disaster risk reduction policies and plans.
- The findings of the work provide a scientific base and present a rationale for mainstreaming climate change adaptation and disaster risk reduction into the overall natural resource governance process at watershed level.
- The study presents a model of community centric and participatory approach of climate change adaptation and disaster management in

underdeveloped and marginalized mountain rural environment that could be replicated all across the Himalayan terrain and mountain regions of the developing and less developed countries

4.3 Take Away for Policy Planners

The availability of and access to food is largely determined by community food purchasing power and infrastructural facilities for the supply and distribution of food in the region. The climate change, particularly the changing pattern of rainfall and increasing frequency and severity of extreme weather events have drastically reduced food production, decreased rural livelihood opportunities, and consequently increased the vulnerability of large proportion of population to food insecurity. The study clearly indicated that the steadily mounting food deficit and declining food purchasing capacity are likely to further undermine the food security of local communities in coming years.

Besides, the continuing inflationary trend in the prices of food commodities may further reduce the access to food of local people. The long-term impacts of changing climatic conditions and increasing frequency and severity of climate change induced natural disasters would certainly change the conditions for food production in Himalaya through influencing the cropping pattern, crop rotation, cropping strength, and cropping intensity; and thus increase the vulnerability of local communities to food insecurity. This will have long-term impacts on food security of the region in terms of quantity as well as quality of food affecting particularly the poor and socially marginalized people which constitute nearly 75% of the total population.

Moreover, conventional adaptation practices and coping mechanisms to climate change and natural disasters are losing their efficiency, particularly in long-term perspectives, and emphasizing an urgent need for new response strategies to cope with these rapid and unprecedented changes. Nevertheless, practically agriculture will remain as one of the important economic activities in the entire Himalaya, and thus will constitute one of the core components of overall climate change adaptation strategy in the region in times to come. Firstly, the agriculture is not merely an important economic activity and fundamental source of livelihood of local rural communities, but it also constitutes an integral part of their history, traditions, conventions, life-style, traditional resource management practices, and a priceless repository of local ecological knowledge which are essential for adapting to climate

change and coping to natural disasters. Secondly, the Himalayan Mountains have some of the highly productive and agriculturally prosperous valleys and mid-slopes which have still potential of contributing towards the food as well as livelihood security in the region. Thirdly, the potential of varying agro-climatic zones from valleys to higher elevation can be utilized for growing variety of crops and producing seasonal as well off-season agricultural products.

In view of this, capitalizing upon both the socio-cultural and biophysical strength of the mountain ecosystem agriculture has the potential to contribute significantly towards securing sustainable livelihood opportunities, particularly for the poor and marginalized mountain communities as well as an effective climate change adaptation and disaster management strategy. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification of agriculture, horticulture, floriculture, dairying, forestry, and for improving productivity of entire mountain crop and livestock system. In order to attain this, the mountain agriculture should be considered as one of the integral components of an overall, integrated development framework.

The mountain agriculture therefore need to be integrated into ongoing poverty reduction programmes, food and livelihood improvement strategies, rural employment schemes as well as with ecological restoration and climate change adaptation and disaster risk reduction action plans in Himalaya. At the same time, small-scale structural as well biological water harvesting measures, for instance, rainwater harvesting, conservation ponds, and irrigation channels, drip water irrigation; and an early warning system for flash floods and droughts could also contribute towards improving food security enhancing the adaptive capacity of local communities to climate change.

Further, integration of different sectors of Himalayan economy with local agricultural production system, flow of credit to rural areas, access to improved agricultural technology, increased investment in mountain agricultural enterprises, development of marketing and processing facilities and a strong institutional mechanism will not only help in making Himalayan agriculture a sustainable livelihood option but also create employment opportunities both in agricultural and non-agricultural sectors. This would help in reducing the vulnerability of mountain communities to food insecurity on the one hand, while on the other build climate change resilient mountain socio-ecological system through improved management of land, water and forest resources. These circumstances therefore emphasis and underline the urgent need of evolving effective strategies for turning the traditional

agricultural practices into climate smart and disaster resilient integrated farming system through adaptive governance of natural resources.

The experiences from other parts of the world indicate that integrated framing system contributes significantly towards sustainable food production and improving food security in disaster-prone areas, made traditional agriculture more resilient to climate change and helped in the restoration of depleting natural resources. Himalaya provides one of the best examples of integrated mountain farming system evolved through thousands of years of experimentation with fragility, inaccessibility and marginality and resultant low carrying capacity of natural resources.

However, during the recent past the values of traditional farming system have eroded considerably mainly due to population growth, rapid urbanization, depletion of natural resource base, economic globalization and market influences and climate change. However, capitalizing upon both the socio-cultural and biophysical strength of the mountain landscape integrated farming system has the potential to contribute significantly towards attaining food and nutrition security as well as securing viable livelihood opportunities for mountain communities under climate change. The potential of agro-climatic diversity ranging from productive valleys to higher elevation can be optimally utilized for the diversification and integration of agriculture, horticulture, floriculture, dairying, fishing, bee-keeping and forestry at watershed level.

In view of this, the proposed integrated farming system could be extended to the rest of Himalayan region and also to other high mountains in the developing and less developed world. However, in order to attain this, the mountain regions should adopt integrated watershed management approach, and climate resilient farming system should be an integral component of integrated watershed development programme. Further, the mountain agriculture need to be integrated with ongoing various poverty eradication programmes, food and livelihood improvement strategies, women's empowerment and gender mainstreaming schemes; and rural employment schemes as well as with ecological restoration and climate change adaptation mechanism.

Moreover, integration of different sectors of mountain economy with local agricultural production system, flow of credit to rural areas, and increased investment on mountain agricultural enterprises will help in making mountain agriculture economically viable, ecologically conducive, and adaptive to climate change and natural disasters. This would require connecting disciplines, and thus

promote coherence, consistency between agricultural and climate change adaptation policies, research, financial investments and sustainable development programmes.

A multi-stakeholder governance framework involving government agencies, community organisations, CSO's, NGO's, private sector, research centres, funding agencies would be essential to further promote climate resilient agriculture in mountains. This would help different stakeholders contributing towards attaining the Sustainable Development Goals (SDGs) particularly SDG 2 (food security); and SDG 13; SDG 1 (poverty reduction), SDG 11 (resilient communities) and SDG 15 (protect ecosystems). Furthermore, continuing efforts in Climate Resilient Agriculture contribute to the implementation of the UNISDR Sendai Framework for Disaster Risk Reduction, and the UNFCCC Paris Agreement.

Further, The general consensus among climate-models for the Himalayan region is very weak as due to complex terrain and topography and the coarse resolution of global climate models. In view of this, it would be highly imperative to develop improved climate models and downscaling strategies capable of capturing changes in extreme events are essential.

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