LOCKED HOUSES, FALLOW LANDS

Climate Change and Migration in Uttarakhand, India

PIK
Potsdam Institute for Climate Impact Research

International Climate Initiative (IKI)

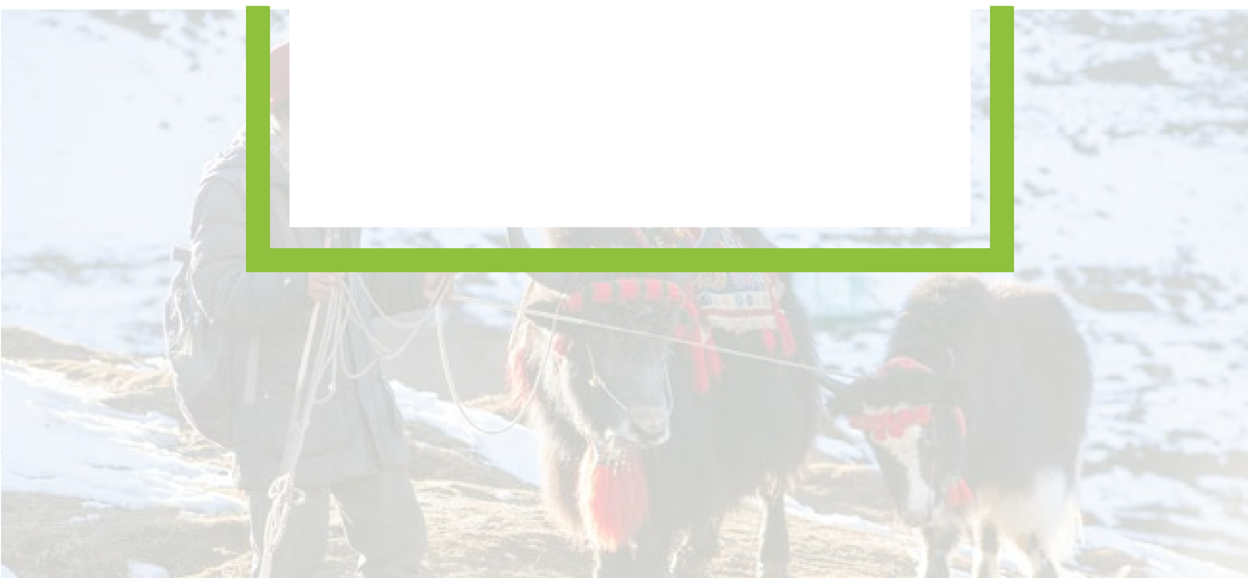
Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag

EPICC

teri The Energy and Resources Institute
Creating Innovative Solutions for a Sustainable Future

LOCKED HOUSES, FALLOW LANDS

Climate Change and Migration in Uttarakhand, India



Potsdam Institute for Climate Impact Research

International Climate Initiative (IKI)

Supported by: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag

EPICC

The Energy and Resources Institute

Creating Innovative Solutions for a Sustainable Future

ISBN: 978-81-7993-6955

Authors: Ms Himani Upadhyay (PIK), Dr Kira Vinke (PIK), Mr Saurabh Bhardwaj (TERI), Ms Mechthild Becker (PIK), Mr Muhammed Irfan (TERI), Mr Nitin Babu George (PIK), Mr Riccardo Biella (PIK), Mr Ponraj Arumugam (PIK), Mr Santosh Kumar Muriki (TERI) and Dr Emanuela Paoletti (PIK).

TERI Press Team

Ms Sushmita Ghosh

Mr Rajiv Sharma

Cover photo

Top photo: View at Dalhousie, Himachal Pradesh, India

© Shutterstock/anjalig04

Bottom photo: Man with two yaks near Auli village, Joshimath town, Uttarakhand.

© Shutterstock/Daniel Prudek

Back cover photo: Gangotri glacier, Uttarakhand, India.

© Unsplash/Himanshu Srivastav

Suggested Citation

Upadhyay, H., Vinke, K., Bhardwaj, S., Becker, M., Irfan, M., George, N.B., Biella, R., Arumugam, P., Murki, S.K., Paoletti, E., 2021. “Locked Houses, Fallow Lands: Climate Change and Migration in Uttarakhand, India” Potsdam Institute for Climate Impact Research (PIK), Potsdam and The Energy and Resources Institute (Teri), New Delhi.

Publisher

The Energy and Resources Institute, New Delhi, India

For more information

Project Monitoring Cell

The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110003, India

Tel: +91 11 2468 2100 or 2468 2111 | **Fax**: +91 11 2468 2144 or 2468 2145| Email: pmc@teri.res.in | Web: www.teriin.org

Table of Contents

List of Figures

List of Tables

List of Boxes

Acknowledgements

This report is a joint effort of the East Africa Peru India Climate Capacities (EPICC) project. The Potsdam Institute for Climate Impact Research (PIK) is leading the execution of the project together with its project partners, The Energy and Resources Institute (TERI) and the Deutscher Wetterdienst (DWD). The EPICC project is part of the International Climate Initiative (IKI: www.international-climate-initiative.com). The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

The preparation of this report was led by Ms Himani Upadhyay[1] (PIK). Other contributors include Dr Kira Vinke (PIK), Mr Saurabh Bhardwaj (TERI), Ms Mechthild Becker (PIK), Mr Muhammed Irfan (TERI), Mr Nitin Babu George (PIK), Mr Riccardo Biella (PIK), Mr Ponraj Arumugam (PIK), Mr Santosh Kumar Muriki (TERI) and Dr Emanuela Paoletti (PIK). This report would not have been possible without the critical reviews and guidance provided by Dr Roman Hoffmann, Dr Emanuela Paoletti and Dr Kira Vinke. We would like to especially thank Prof Hans Joachim Schellnhuber for his guidance.

This report was conceived and conceptualised with Ms Julia Blocher (PIK) and Mr Jonas Bergmann (PIK). Thank you for your support! We are also thankful to Mr Kurt Klein for language editing and Mr Rajiv Sharma (TERI) for layout and design of the report.

[1] Corresponding Author. Himani.Upadhyay@pik-potsdam.de

Foreword

Nestled in the Indian Himalayan Region, the state of Uttarakhand is characterized by snow-covered mountains, dense forests, rich biodiversity, terraced fields, and hills communities with unique heritage and culture. Today, climate change is creating new risks that threaten this very character of Uttarakhand. From unprecedented dengue outbreaks paralyzing the state's health department to the plight of flood-displaced populations, the impacts of climate change are posing new challenges to the state government.

The decade of 2011–2020 was the warmest on record, with 2020 rivalling 2016 as the individual year with the highest global mean surface temperature ever measured. Greenhouse gas emissions are 60% higher now than in 1990, and if this trend continues, the planetary temperature could rise by 3–5 °C by the end of the 21st century. In Uttarakhand, such a global disruption would result in severe regional risks, most notably to the subsistence-based agricultural communities living in the mountains. Currently, a variety of reasons, where deleterious climate impacts grow in importance, are motivating people to migrate from the hills to the plains. And due to this, an increasing number of villages in Uttarakhand are uninhabited. However, if temperatures continue to rise, livelihoods across the entire state could be destroyed, leading to significant outmigration.

The year 2020 will go down in history as the time when the world stood still due to the Covid-19 pandemic, yet millions of people were forced to be on the move. Before the pandemic, migrants arriving in urban centres such as New Delhi or Kolkata were largely an invisible population. However, as India entered into a lockdown, migrant workers lost their jobs and sometimes even their place to live. With the transport systems shutting down, they were left with no other option than to return to their native location on foot. A mass reverse migration unfolded. Within India, estimates show that 40 million migrants were impacted by the lockdown. These migrant populations work largely in the informal sector, often on daily wages, and live hand to mouth. Missing just one day's income can make buying food or finding shelter impossible. Therefore, these human beings are the most vulnerable in society, pushed into utterly precarious conditions by the pandemic. The lockdown led to long periods of joblessness, so 71% of return migrants in Uttarakhand decided to stay there, thus interrupting the flow of urban–rural remittances.

The Covid-19 pandemic exhibits many parallels to the climate crisis. Both predicaments show that a multilateral effort is required to address global challenges and that time is of essence when nonlinear dynamics are at play. The strong measures taken worldwide to fight the Corona pandemic prove that societies are indeed willing to put the health and wellbeing of people above economic profits.

This report is an outcome of a successful collaboration between the Potsdam Institute for Climate Impact Research (PIK), Germany and The Energy and Resources Institute (TERI), India, within the framework of the "East Africa-Peru-India-Climate Capacities" project (EPICC). It is one of the first assessments done on climate change and migration at the sub-national level in India. The report provides an integrated assessment, employing the latest climate data to arrive at granular environmental risks and the impacts thereof on migration conditions. It particularly explores the role of agriculture to better understand climate–migration linkages.

The analysis is enriched with concrete recommendations for policymaking and research. The report identifies three main areas of action, namely (i) preparing for demographic changes resulting from migration; (ii) creating alternate livelihood options in the hill districts to revitalize the economy; and (iii) to revisit the state's climate change action plan as well as the state's agricultural policies in the wake of outmigration from hill districts. This report explicitly aims to provide an evidence-based foundation for a science–policy dialogue. It can serve to initiate conversations on the topic and strengthen climate action plans and migration policies.

Despite the stymying Corona crisis, global greenhouse gas concentrations in the atmosphere have kept on increasing in 2020. While countries invest tremendous amounts of money in developing vaccines against the COVID-19 virus family, one must not forget that there is no vaccine against global heating. The planetary surface temperature needs to be kept below 2 °C so that rural hill communities in Uttarakhand can continue to live in the places they call home.

Prof. Dr. Hans Joachim Schellnhuber
Director Emeritus
Potsdam Institute for Climate Impact Research
Germany

Dr. Ajay Mathur
Director General
The Energy and Resources Institute
India

Executive Summary

The image of Uttarakhand is shaped by the snow-covered mountains of the Indian Himalayas, the springs of the Ganga[2] and Yamuna rivers, and its numerous lush green valleys. The North Indian state was founded in 2000 when it was split from Uttar Pradesh. Although it was created to provide a separate administrative and political unit for people who lived in the mountains, Uttarakhand continues to include extensive plains areas. The geographical and socio-economic differences between the hills and the plains have only widened in recent years. Urbanisation, dwindling economic opportunities in the agricultural sector and societal disintegration in rural communities have triggered outmigration from its hill districts, leading to depopulation and abandoned villages. Climate change impacts that have emerged over the past decades – such as rising temperatures, increasing glacial melt and changing rainfall patterns – are projected to intensify over the course of this century. This report explores how these impacts could affect livelihoods and thereby shape migration patterns in Uttarakhand.

Demographics

Uttarakhand is home to over ten million people but is one of the few Indian states which is losing population, as some migrants are leaving the state altogether. About 70% of migrants are internal, however, these mostly move from the hills to the plains and valleys. Consequently, the share of its residents living in hill districts has declined from nearly 53% in 2001 to about 48% in 2011. The hill districts of Almora and Pauri Garhwal both recorded negative population growth between 2001 and 2011. The two districts combined showed an absolute decline of 17,868 persons over the decade. About two-thirds of the state's population lives in rural areas, and the same share of people work in agriculture. Uttarakhand is significantly less densely populated than most Indian states, with 189 persons/sq kilometre (the population density for India as a whole is 455/sq km). In recent years, urban centres in plains districts have attracted a growing number of agricultural workers from the hills, in line with India's general urbanisation rate of about 2.4% per year. Around 30.2% of Uttarakhand is urbanised (in 2011). The state has a gender ratio of 963 females per 1000 males (in 2011), while the total fertility rate is 1.9 (in 2016).

Differences between plains and hill districts

The hill districts of Uttarakhand are less developed than the plains districts, with lower average income levels and human development index scores. This difference stems mainly from the economic drawing power of the urban centres in the plains districts which have undergone a large-scale industrialisation process. The state's capital city of Dehradun, for example, offers employment opportunities in the tertiary sectors such as hotels, transportation and communication services with superior pay levels to those available in the hill districts' traditional small-scale agriculture.

[2] Also known as the Ganges.

Migration

The Census of India for 2011 put the total number of migrants in Uttarakhand at 4,317,454, with considerably more female migrants (2,836,147) than male migrants (1,481,307). The rural–urban divide is probably the most important explanatory factor for the state's migration dynamics. The inability to diversify livelihoods in rural areas has been identified as the most relevant push factor for outmigration (50%), followed by lack of educational institutions (15%) and healthcare facilities (9%). The largest group of migrants (42%) are between 26 and 35 years old, and two-thirds of the migrants relocate within the state. Migration also generally means a shift away from agriculture as a source of employment. Because of outmigration, the agricultural labour force in the hill districts is decreasing, which means that the remaining, often elderly, people must each carry out more tasks. Women do a large share of farm work in the hills of Uttarakhand. The combination of a shrinking labour force and resulting lack of income have caused complete outmigration in many communities. This dynamic has led to the abandonment of 734 villages since 2011, signifying the extent of depopulation in rural hill areas.

Remittances

Remittances are integral to the socio-economic development of Uttarakhand. The state is renowned for its 'money order economy' based on the remittances migrants send via postal money orders to their families. Three-quarters of all migrants remit money, most often monthly (42%), to their place of origin. In the hill districts of Champawat, Chamoli and Rudraprayag, and the plains districts of Dehradun and Haridwar, the proportion is even higher (around 80%). The largest share of these remittances is used for daily household consumption needs such as food and clothing, followed by education and health expenses, and a small amount is allocated to pay for agricultural labour and make investments in agriculture.

Climate

Climate change impacts have started to affect peoples' livelihoods in Uttarakhand, leading them to modify some of their agricultural practices. But projections indicate that growing climatic pressures will require more significant adaptation efforts in the future. This report discusses historical trends and variability in the state, as well as future projections for temperature, precipitation and extreme climatic conditions. The data is drawn from an exhaustive literature review and additional original analysis for two emissions scenarios, RCP4.5 and RCP8.5. As neither of these analyses produced outcomes in line with the Paris Agreement's temperature limits, they indicate what is likely to happen if countries fail to comply with the emission.

Temperature

Uttarakhand registered an increase of 0.46 °C in mean annual temperature between 1911 and 2011, significantly less than the global mean surface temperature rise of 0.87 °C reached in the 2006–2015 time period (relative to an 1850–1900 baseline). Hill districts such as Uttarkashi, Chamoli, Rudraprayag and Pithoragarh showed the greatest warming; while the plains districts of Haridwar, Dehradun, and Pauri Garhwal saw relatively less warming. The evidence suggests that the state's mountain regions are experiencing 'elevation-dependent warming' – a phenomenon caused by the interaction of factors such as snow albedo, cloud cover, atmospheric, and surface water vapour changes, and aerosols with the land surface. The result is an amplified rate of warming at higher elevations, which experience more rapid and acute changes in temperature than lower-elevation regions.

In the sixty-three years from 1951 to 2013, the state's annual maximum temperature has increased by 0.42 °C, and the annual minimum temperature has decreased by –0.25 °C, consistent with the evidence of receding snowlines and glacier melt. In the future, the most significant changes in both maximum and minimum temperatures are projected to occur during the pre-monsoon season from March to May, which carries implications for crop development.

Moreover, these temperature extremes will intensify. Compared to a 1971–2005 baseline, Uttarakhand's average annual maximum temperature under the RCP4.5 scenario is projected to increase by 1.6 °C in the near-future (2021–2050), 2.4 °C in the mid-future (2051–2080), and 2.7 °C for the far-future (2081–2099). Under the RCP8.5 scenario, it is projected to increase by 1.9 °C in the near-future, 3.8 °C in the mid-future, and 5.3 °C for the far-future. An increase of more than 5 °C in maximum temperature could significantly inhibit outdoor work, especially in the plains districts' lower elevations. Warm and very warm days are also projected to increase. Warm days refer to the percentage of days when the temparture is more than 90th percentile of the baseline (1971–2005), and very warm days refer to the percentage of days when the maximum temparture is more than 95th percentile of the baseline (1971–2005).

Average annual minimum temperatures for the RCP4.5 scenario are projected to increase by 1.5 °C in the near-future, 2.4 °C in the mid-future, and by 2.7 °C for the far-future. Under the RCP8.5 scenario, the projected increases are 1.8 °C in the near-future, 3.7 °C in the mid-future, and 5.2 °C for the far-future. Compared to other parts in the state, the Northern hill districts of Uttarkashi, Chamoli, and Pithoragarh show the most significant projected changes in both minimum and maximum temperatures for both the RCP4.5 and RCP8.5 scenarios.

Rainfall

The state of Uttarakhand and its inhabitants depend on timely summer monsoons to provide sufficient precipitation for agriculture, as the great majority of farming is rain-fed and lacks modern irrigation. There has been notable interannual variability in rainfall over the last century with the number of rainy days declining since the 1990s. In particular, the state's hilly regions have become drier. The total amount for rainfall has not shown a substantial decrease, however, implying fewer but more extreme rainfall events have occurred in recent decades.

Uttarakhand has a complex rainfall pattern, mainly due to its orography, which compounds the difficulty of projecting future rainfall trends. Nevertheless, some estimates can be made. Average annual rainfall is projected to increase under RCP4.5 by about 6% in the near-future, 10% in the mid-future, and 16% in the far-future. Under RCP8.5 the projected increases are 8%, 20%, and 32% respectively, for the same periods. The biggest projected change is expected during the monsoon season of June to September. Southern districts such as Udham Singh Nagar, Nainital, Champawat, and Pauri Garhwal have the highest projected increases in annual average rainfall for the near-future period, compared to other parts of the state, for both the RCP4.5 and the RCP8.5 scenarios. Rainfall during the winter season from December to February is projected to decrease under both the scenarios (for all time periods), meaning it may intensify in other months. In fact, all districts of Uttarakhand are projected to show increased heavy rainfall events under both RCP4.5 and RCP8.5, although the number of heavy rainfall days is expected to be higher in RCP8.5.

In addition to its complex orography, Uttarakhand has too few meteorological stations, resulting in spotty evidence that hinders progress in understanding the monsoon's spatiotemporal features. Collecting sufficient data would require higher investment in high-resolution, regional-scale models that could provide boundary conditions which simulate rainfall patterns at the western Himalayan foothills with higher precision.

Migration and climate change

Climate change is functioning as a risk modifier influencing existing population movements in Uttarakhand. Seventy per cent of the population is dependent on rain-fed agriculture that is not highly productive. Climate change has led to further decline in agricultural productivity over the last two decades, adding to outmigration pressures. Observations show that reduced and uneven rainfall has already decreased crop yields, while projections for both RCP4.5 and RCP8.5 indicate increased agriculture water stress and a further decrease in yields. In many higher elevation areas, climate change is causing mountain springs which provide the only source of water to dry up, underscoring the nexus between climate impacts, livelihoods and migration. Figure 1 outlines the projected climatic risks to agriculture-based livelihoods in the state. The combination of existing outmigration patterns and projected climate change impacts – mainly in the north, central, and western regions – indicates that livelihoods in these regions are likely to be more affected.

Unsurprisingly, an analysis of conditions in the Indian Himalayas shows that migration increases as environmental conditions reduce income. As people migrate, their communities are left with fewer agricultural workers, which can further depress incomes. Left with limited people and limited options, rural hill populations may become vulnerable to forced migration and displacement. This self-reinforcing process erodes local adaptive capacities and decreases social capital, which can ultimately lead to abandoned settlements (or 'ghost villages' as they are popularly called in Uttarakhand).

While some people may be forced to migrate, others can be immobilised by family obligations or lack of resources. In Uttarakhand, women who stay back while the men migrate are left with the double responsibility of managing both farm and household activities – while also coping with climate impacts. Although the most vulnerable strata of society may migrate in certain situations, they lack the alternatives available to those with more resources. As climate change impacts become more pronounced in the future, thresholds may be crossed, leaving the economically disadvantaged trapped in place.

However, the long-term climate change could lead to a demographic reversal. Despite the current trend of outmigration from hill districts, in the future high-elevation zones may offer relatively favourable climatic conditions given the high warming levels projected for low-elevation areas.

Research gaps

More research is needed to identify and understand all the linkages between climate change and migration in Uttarakhand. Which contextual factors, for instance, determine why some people migrate and some chose to stay despite living under the same or similar changing climatic conditions? An improved and more comprehensive analysis of such linkages could improve the effectiveness of adaptation planning.

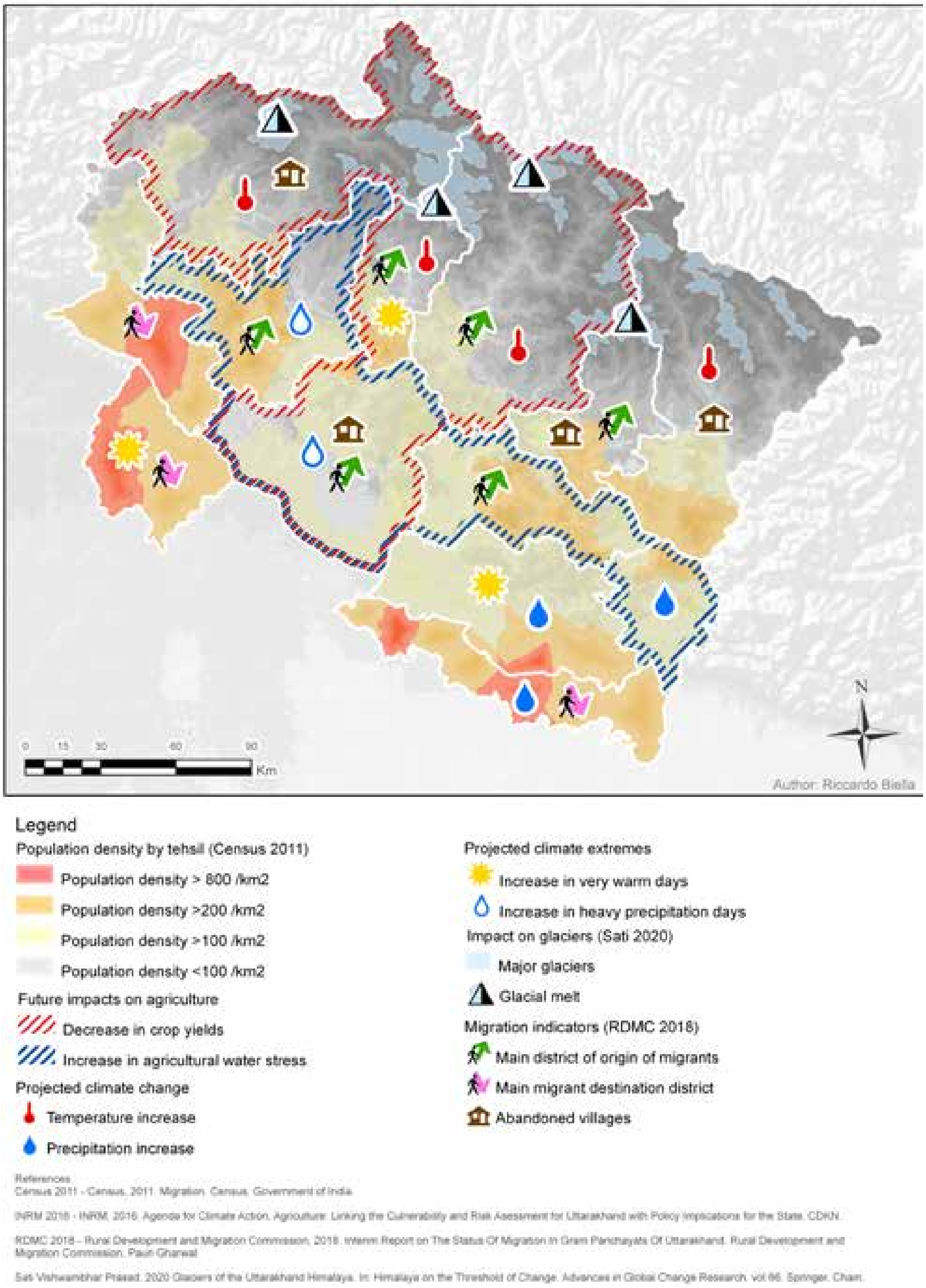


Figure 1: Livelihood risk map of Uttarakhand outlining projected climate change effects, projected climate extremes, impacts on agriculture, migration indicators, and population density. Hill districts in the north, west, and central part of the state are more affected and likely to face higher livelihood risks as majority of the population is dependent on subsistence-based, rain-fed agriculture – adding to the existing outmigration from hill to plains districts

Understanding different types of mobility in a changing climate requires more investigation. Mobility in Uttarakhand is usually discussed under the umbrella of migration, either as permanent or as semi-permanent. But other forms of mobility are relevant in Uttarakhand and merit consideration. These include transhumant pastoralism, seasonal migration, and displacement – all of which could be impacted by climate change.

More research is needed on gendered effects of climate change and migration in Uttarakhand. Empirical evidence should be developed about how women and men may reach different migration decisions. As already mentioned, the women who remain after men migrate must manage both agricultural and household activities while coping with climate change. Yet we cannot merely assume that married women have less choice and are more likely to stay, while unmarried women have more choice and are more likely to migrate. Such propositions must be tested against actual data.

Which populations choose to stay and which are unable to move should be identified and their motivations analysed. Some people affected by environmental degradation and disasters may be unable to migrate. This might be because of a lack of financial resources or household circumstances like looking after the elderly. More information is needed about the effects of these factors. Similarly, why do some people voluntarily stay under unfavourable conditions that cause many others to leave? Non-migration deserves investigation as much as migration does.

Data needs

Comparable, longitudinal, and georeferenced data is essential, but not generally available. In particular, time-series data of environmental and demographic variables, at both temporal and spatial scales, is required to produce more accurate analyses. Efforts should be made to collect the finest-resolution data at the household and village levels. Long-term longitudinal data that can be compared and geotagged could help assess migration patterns to assist informed policymaking.

Uttarakhand's lack of good-quality, historical meteorological data inevitably limits climate research in the state. The number and sophistication of its meteorological stations should be increased and improved. More and more accurate observations are critical to validate results from regional-scale models. These can then be adjusted to better represent conditions such as elevation patterns, orographic lifting, and other complex topographical features.

Investments in statistical skills and data infrastructure need to be prioritised. Migration data captured by the national population or migration censuses usually does not include how environmental degradation, climate change impacts, or disasters affect migration. Such improvements could complement the necessary training and capacity building of institutions and agencies responsible for data collection.

Recommendations for policymakers

Climate change policies and plans should recognise the linkages between climate change and migration. The *Uttarakhand Action Plan on Climate Change* (2014) already recognises the need for a full-scale study to understand the possible impacts of climate change on migration. The first step in this direction could be to integrate current and likely future linkages into existing vulnerability assessments, such as those done for the Indian Himalayan Region

(IHR) by the Indian government's Department of Science and Technology (DST) in 2019, or INRM Consultants' 2016 vulnerability assessment at the district and block level for the Government of Uttarakhand. Other steps include:

- **Preparing for demographic changes resulting from migration**. In line with the principles of the *Global Compact on Safe, Orderly and Regular Migration* (GCM), to which India is a signatory, the government is pledged to ensure the safe and orderly migration of those on the move. Helping those who migrate, however, should be combined with strategies to support *in situ* climate adaptation options which allow people to adjust without leaving home.

- **Creating alternate livelihood options in the hill districts to revitalise the economy.** For instance, Uttarakhand is blessed with many natural assets, which could be harnessed for developing sustainable eco-parks. Promoting homestays in villages could create employment opportunities in rural areas. Sustainable, systematic tourism might be an effective option to convert the historical economic disadvantages of the hill districts into an asset. Tourism is just one possibility, of course, and others should also be explored.

- **Revisiting agricultural policies**. Declining agricultural productivity is a key driver of outmigration in Uttarakhand. Farmers need support to increase and improve their sources of income. Agriculture extension services could provide education and training to update their farming practices and diversify their crops. For example, growing more cash crops like mushrooms that require less water. Or intercropping medicinal and aromatic plants with food grains. These have a high return on investment and are in great demand in the cosmetics and pharmaceutical sectors. Farmers could be assisted with the development of irrigation channels and rainwater harvesting structures, the provision of better quality seed, information on crop and animal insurance, improved access and connectivity to markets, or better marketing of horticulture crops such as apples.

In short, the postcard image of Uttarakhand – characterised by its photogenic mountains, rivers, and valleys – belies the serious challenges climate change will bring to the rural subsistence farmers of the state's hill districts as well as to urban centres in the valleys. Nevertheless, if warming can be kept below 2 °C, meaningful opportunities to ameliorate its impacts will continue to exist. The stabilisation of rural livelihoods and investments in improved traditional agriculture are crucial steppingstones to a sustainable future for Uttarakhand.

INTRODUCTION

Terrace farming in hills of Uttarakhand, India

© Unsplash/Ketan Pandey

1 Introduction

Climate change is an undeniable fact, and its effects are identifiable in many parts of the world. This is particularly true in developing and emerging economies which have limited capacity to respond. This report outlines how this process is playing out in one such case, the North-Indian state of Uttarakhand. Multiple drivers of change, including climate change are acting on natural resource-dependent communities of Uttarakhand. Economic growth, improved communication networks, better roads have led to rising aspirations and influenced mobility in the state. The spread of mobile phones and Internet availability have increased exposure to the outside world and helped foster previously unimaginable links and networks, even in remote areas of the state (Mehta, 2014). A growing network of roads has led to more connectivity. These changes opened doors to opportunities in urban centres with a trend of outmigration from villages in the hills to urban centres in the plains. Outmigration has emerged as a key factor for depopulation in the hill districts. In addition to this, climate change is acting as risk modifier influencing population movements.

People in Uttarakhand are already experiencing climate change impacts such as changing temperatures, upward-moving snowlines, receding glaciers, erratic rainfall, reduction of snow in the winter, increased heat, advancing cropping seasons, shifting cultivation zones for certain crops, and drying up of perennial streams (Government of Uttarakhand [GU], 2014). As the majority of the state's population lives in the rural hill areas and is dependent on rain-fed agriculture, these impacts are having severe consequences for people's livelihoods.

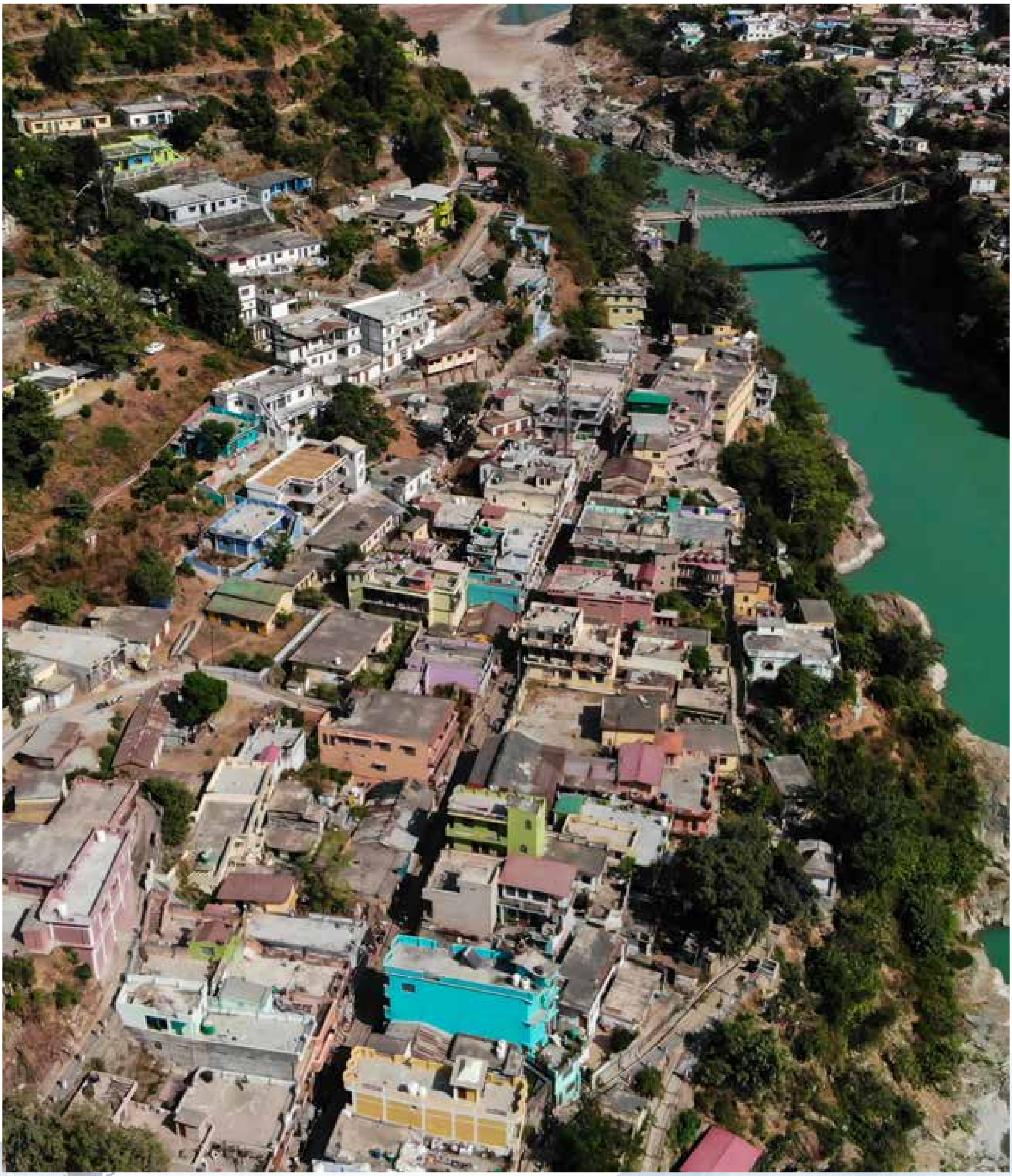
The state of Uttarakhand is divided into two main geographical zones: hill districts in the Himalayas and plains districts which include several large urban centres. A variety of reasons, among them these increasingly severe climate impacts, are motivating people to migrate from hill to the plains districts. On the one hand, these movements have led to depopulated villages and a shrinking agricultural sector in hill districts; on the other hand, they have put additional pressure on the already densely populated cities in the plains. The result has been urban overcrowding, competition for resources, and an increasing number of slums (Habeeb and Javaid, 2019; Rural Development and Migration Commission, 2018; Sati, 2020). The depopulation of hill-district villages has led to labour shortages, which in turn have pushed further outmigration from the villages because people who remain are overburdened with agricultural labour, and hence, cannot effectively practice traditional agriculture. Moreover, outmigration can also tear the social fabric in places of origin. The state government has identified both climate change and permanent outmigration from hill districts as serious challenges (GU, 2014; Rural Development and Migration Commission, 2018).

In Uttarakhand, climate change and migration have featured in important policy documents (for climate change, refer to *Uttarakhand Action Plan on Climate Change*, 2014; for migration, see the *Report on Status of Migration in Gram Panchayats of Uttarakhand*, Rural Development and Migration Commission, 2018). While more information on climate change and migration in Uttarakhand exists, it is often available only separately, scattered across a wide range of state departments and agencies in different reports, policies, and plans. Hence, it is generally difficult to access. Moreover, a few studies have focused on the linkages between migration and climate change in Uttarakhand. This report aims to bring together as much of the existing information as possible, on both climate change and migration patterns, to help fill this gap. It assesses the critical role of climate change effects on agriculture and its linkages to rural livelihoods and migration. By enhancing knowledge on the topic, this report should provide information and guidance about the state's climate change and migration policies.

This report is based on a review of the state-of-the-art literature and draws from a variety of sources, including scientific publications, government reports, policy documents, working papers, and statistical data. It begins with an overview of Uttarakhand in Chapter 2, which describes trends in its economy, population (and depopulation), poverty, regional inequalities, and human development index since the state's formation in 2000. Chapter 3 focuses on climate change variability and vulnerability in Uttarakhand – including rainfall and temperature trends and projections, extreme weather events, and a discussion of district-wise vulnerability. An analysis of migration follows in Chapter 4, including historical trends, current patterns, reasons for migration, migrant destinations, permanent and non-permanent movements, uninhabited villages, and depopulation. After considering the evidence on climate change trends and migration patterns, chapter 5 analyses the linkages between climate change and migration with a focus on agriculture. Chapter 6 discusses existing policy frameworks in the context of migration. Lastly, in Chapter 7, gaps in research, data needs, and priorities are outlined as policy recommendations.

This report provides an evidence-based overview of climate change trends and migration patterns, and their linkages, in Uttarakhand. It is intended to initiate academic and policy discussions on this subject, which will only grow in importance in the future.

UTTARAKHAND OVERVIEW



Aerial view of Srinagar city in Pauri Garhwal, Uttarakhand. Located at the bank of River Alaknanda.

2 Uttarakhand Overview

On 9 November 2000, Uttarakhand became the twenty-seventh state of the Republic of India, following a long struggle for statehood by its people (Kumar, 2011; Linkenbach, 2002; Pathak, 1999). Uttarakhand comprises thirteen northern districts carved from the state of Uttar Pradesh (UP).[3] Located at the foothills of the Himalayas, the particular characteristics of mountain life play a central role in the lives and livelihoods of its people. They demanded a separate state to protect their rights, as they felt the interests of mountain people were underrepresented in the political and developmental processes of UP, a predominantly plains state (see Box 8 in the Appendix at the end of the report for an overview of the Uttarakhand Movement). Despite the fact that hill-centric development was a decisive reason for a separate state, these plains region have benefitted disproportionally from economic investments (see Section 2.3). This dynamic has increased regional disparities, which in turn influence and reinforce migration processes from the hills to the plains. However, the decision to migrate usually depends on a complex interplay of factors: not just economic, but social, political, environmental, among others (Foresight, 2011). Thus, a broader picture is needed to understand why people may migrate or stay, when looking at the climate–migration nexus in a specific region. This section aims to provide such a broad overview of Uttarakhand, discussing its physiography, population dynamics, human development indicators, economic growth, and regional inequalities.

Uttarakhand lies in the northern part of India (Figure 2). It covers an area of 53,483 km^2, or about 1.63% of the total area of India. The state shares international borders with China (Tibet) in the north and Nepal in the east, inter-state boundaries with Himachal Pradesh in the west and north-west, and UP in the south. Uttarakhand derives its name from the combination of the Hindi words *uttara*, meaning 'north', and *khand*, meaning 'land', to mean 'Northern Land'. The state is also known as *dev bhoomi*, the 'Land of the Gods', as it is home to some of the most sacred Hindu places of worship. Two of the religion's holiest rivers, the Ganga (also known as the Ganges), and the Yamuna, originate in the state's mountains.

[3] At the time of its formation, the new state was called Uttaranchal. In 2007 it was renamed Uttarakhand.

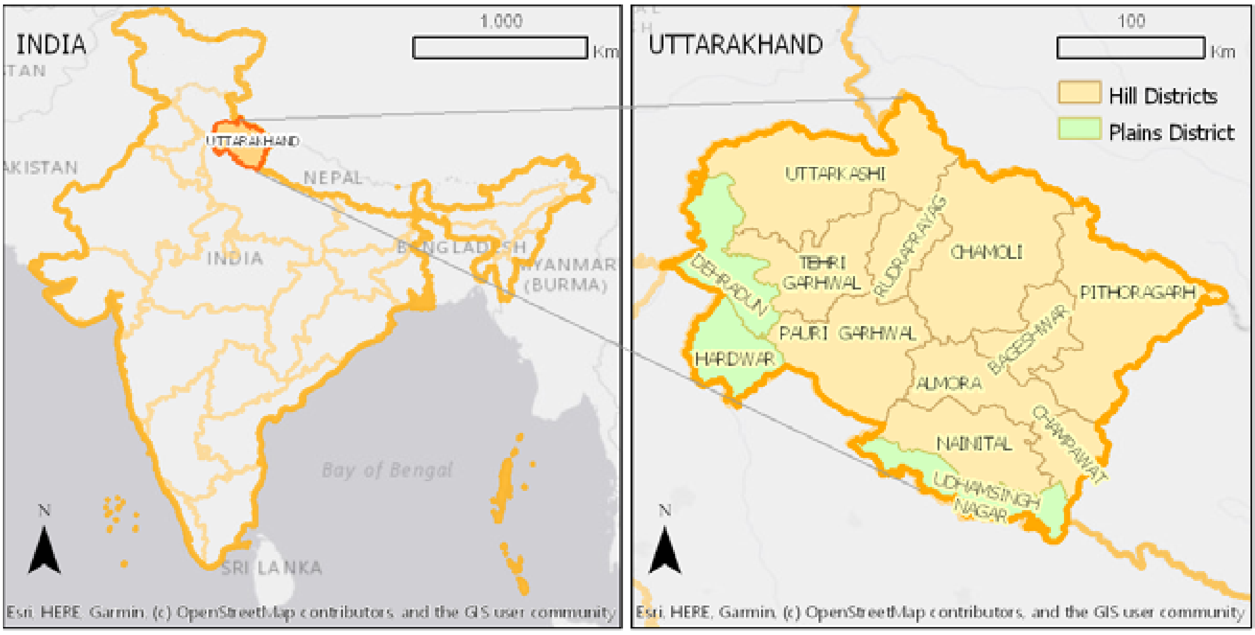


Figure 2: Map of India, highlighting the state of Uttarakhand; on the right the thirteen districts of Uttarakhand
Image Credit: Riccardo Biella, PIK

Uttarakhand is one of the ten Indian Himalayan states. Most of Uttarakhand's terrain can be classified as mountainous. The most commonly used definition of mountains was developed by the United Nations Environment Programme (UNEP) World Conservation Monitoring Centre [based on (Kapos et al., 2000)]. It divides mountain areas into seven classes based on altitude and slope (see legend of Figure 3 for the seven classes). The application of this methodology to the state of Uttarakhand leads to about 85% of the state being classified as one of six classes of a mountain and over 30% being at elevation higher than 2500 m (mountain classes 1, 2, and 3) (Figure 3). Its highest peaks are Bandarpunch (6315 m) in the west, and Trisul (7120 m) and Nanda Devi (7817 m) in the east. Elevations range from 210 m to as high as 7817 m, leading to differences in climate and flora and fauna and distinct physiographic zones. The region is drained by the rivers Tons and Yamuna in the west; by the river Bhagirathi and Alakananda (which is known as the Ganga from the town of Devprayag onwards) in the central part; and by the rivers Kali and Ramganga in the east. Uttarakhand is rich in forest and other natural resources and, due to the state's location in the Himalayan mountain range, vegetation varies significantly with altitude [Forest Survey of India (FSI), 2019]. In the higher altitudes, the forests consist of oak, fir, and spruce, while pine dominates in the lower ranges. Terraced fields may extend up to about 3000 m, and crops vary according to irrigation facilities and altitude (rice, millet, wheat, pulses, potatoes, apples, oranges, etc.). The topography of the state is highly varied, characterised by plains areas in the southern parts and hilly and mountainous terrain[4] with valleys and deep canyons in the rest. This combination of hills and plains is an essential characteristic of Uttarakhand, which affects population demographics, local identities[5], livelihoods, and migration patterns.

[4] In the same district, some parts could be hilly while, as one goes up the elevation, it becomes a mountain. For purposes of this report, hills and mountains are at times used interchangeably.

[5] People in the hills or mountains identify themselves as pahari, a Hindi term which translates to people who live in the mountains/hills, while people who live in the plains are locally referred to as maidani.

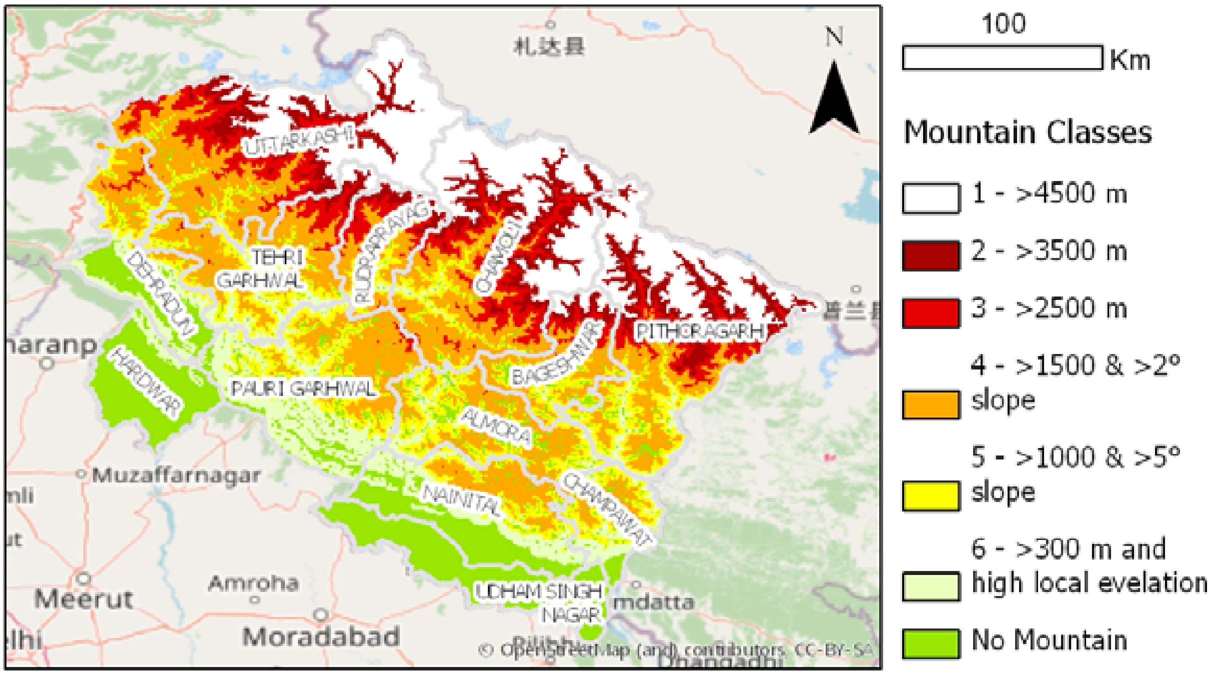


Figure 3: State of Uttarakhand classified according to the UNEP classification for mountains
Source: Kapos et al., 2000
Image Credit: Riccardo Biella, PIK

Administratively, the state is divided into two divisions, Garhwal and Kumaon. They together comprise thirteen districts, 95 development blocks, and 7950 gram panchayats (village councils). There are 16,793 census villages (Census, 2011a), of which 15745 are inhabited, and 1048 are uninhabited (Census, 2011a). In 2011, about 80% of the villages in Uttarakhand had a population of fewer than 500 people (Rural Development and Migration Commission, 2018).

The distinction between the plains and the hill areas is of particular relevance for this report. Livelihoods and economic prospects significantly differ between these areas, with implications for migration dynamics in Uttarakhand, as discussed above. The plains mainly consist of the three southern districts of Dehradun, Haridwar, and Udham Singh Nagar; the remaining ten districts – Almora, Bageshwar, Chamoli, Champawat, Nainital, Pauri Garhwal, Pithoragarh, Rudraprayag, Tehri, and Uttarkashi – make up the hill region. Nearly half (48.0%) of the state's population lives in the hill region, a large majority (85.0%) of whom reside in rural areas. Currently, 67.9% of Uttarakhand's total rural population resides in the hill districts (Planning Commission, GU, 2017). Table 1 provides an overview of the state, including information on its geographical, demographic, administrative, migration, and labour characteristics.

Table 1: Uttarakhand overview

State formation		9 November 2000
Capital		Dehradun[6]
Geographical overview		
Total area		53,483 Km^2
Total hill area		46,035 Km^2
Total plains area		7,448 Km^2
Total forest area		38,000 Km^2
Administrative overview		
Total number of districts		13
Development blocks		95
Municipal corporations (as of 2018)		8
Towns (as per 2011 Census)		41
Villages (as per 2011 Census)		16,793
Uninhabited villages (as per 2011 Census)		1,048
Demographic overview		
Total population (as per 2011 Census)		10,086,292
Male population (as per 2011 Census)		5,138,000
Female population (as per 2011 Census)		4,948,000
Rural population (as per 2011 Census)		7,037,000
% Of rural population	In 2001	74.33%
	In 2011	69.45%
Urban population (as per 2011 Census)		3,050,000
% Of urban population	In 2001	25.6%
	In 2011	30.5%
Density of population (as per 2011 Census)		189 Persons/ Km^2
Gender ratio		963 Females per 1000 males
Literacy rate (as per 2011 Census)		78.80%
Human Development Index (HDI)		0.718

6 In June 2020, Gairsain, a small town located in the middle of Uttarakhand in the hill district of Chamoli, was officially declared to be the state's summer capital. In what has been a hot political topic since even before the state was officially formed, the hope is that the declaration of Gairsain as the state's summer capital will foster development in the hills. More information can be found here: https://www.hindustantimes.com/travel/uttarakhand-gets-gairsain-as-its-summer-capital-after-governor-gives-her-assent/story-tK6nb6XZG7aeSeF9GFXwnO.html.

Labour force overview	
Main workers[7] (as per 2011 Census)	28.71%
– Cultivators[8] (as per 2011 Census)	10.46%
– Agricultural labourers[9] (as per 2011 Census)	2.47%
– Household industry workers[10] (as per 2011 Census)	0.77%
– Other workers (as per 2011 Census)	15.1%
Marginal workers[11] (as per 2011 Census)	10.1%
– Cultivators (as per 2011 Census)	5.35%
– Agricultural labourers (as per 2011 Census)	1.56%
– Household industry workers (as per 2011 Census)	0.37%
– Other workers (as per 2011 Census)	2.73%

Source: Population Census 2011(Census, 2011c); Uttarakhand State Economic Survey 2016-17 (Planning Commission, GU, 2017)

2.1 Population Dynamics

According to 2011 Census data, Uttarakhand has a population of 1.01 crores (approx. 10.086 million), an increase from 84.89 lakh (approx. 8.5 million) since the 2001 Census (Figure 4) (Census, 2011c; Planning Commission, Government of Uttarakhand, 2017). The decadal growth rate of 19.17% in this period was higher than the national average of 17.64%. Nearly 70% of Uttarakhand's population lives in rural areas, a decline of almost 5% since the 2001 Census. As discussed above, about 68% of Uttarakhand's total rural population lives in the ten hill districts (Planning Commission, GU, 2017). For definition of rural and urban area, refer to Box 1.

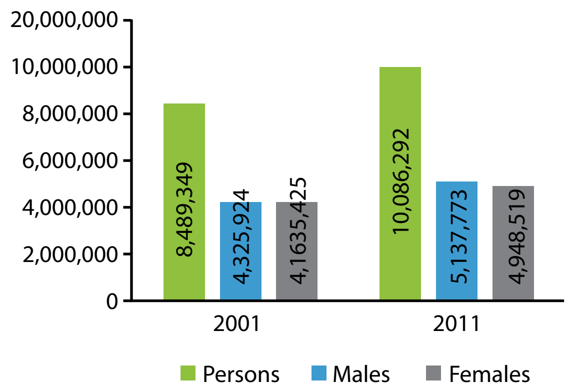


Figure 4: Uttarakhand population profile comparing 2001 and 2011 Census
Data Source: Census, 2011

7 In the Census, main workers are defined as '[w]orkers who worked for more than 6 months (180 days) in the reference period' (Census, 2011b, p. 16).

8 For purpose of the Census, a cultivator is someone 'engaged in cultivation of land owned or held from Government or held from private persons or institutions for payment in money, kind or share. Cultivation includes effective supervision or direction in cultivation. A person who has given out her/his land to another person or persons or institution(s) for cultivation for money, kind, or share of crop and who does not even supervise or direct cultivate on land, is not treated as cultivator' (Census, 2011b, p. 16).

9 In the Census, an agricultural labourer is defined as '[a] person who works on another person's land for wages in money or kind or share [...] She or he has no risk in the cultivation, but merely works on another person's land for wages. An agricultural labourer has no right of lease or contract on land on which she/he works' (Census, 2011b, p. 16).

10 The Census defines Household Industry as 'an industry conducted by one or more members of the household at home or within the village in rural areas and only within the precincts of the house where the household lives in urban areas. The larger proportion of workers in the household industry consists of members of the household. The industry is not run on the scale of a "registered factory where more than 10 persons with power or 20 persons without power is in use as it would qualify or has to be registered under the Indian Factories Act" (Census, 2011b, p. 16).

11 Marginal Workers are '[w]orkers who worked for less than six months (180 days) in the reference period' (Census, 2011b, p. 16).

Box 1: Definition of Urban and Rural Areas

The Census of India 2011 defines urban and rural areas as follows:

Urban Area:

1. All statutory places with a municipality, corporation, cantonment board, or notified town area committee
2. All other places which satisfy the following criteria:
   a. A minimum population of 5000
   b. At least 75% of the male working population is engaged in non-agricultural pursuits
   c. A population density of at least 400 persons per/km^2

Rural Area: All areas not defined as urban area are considered rural. The basic unit for rural areas is the revenue village. The revenue village need not be a single agglomeration of habitations. But the revenue village has a definite surveyed boundary and each village is a separate administrative unit with separate village accounts. It may have one or more hamlets. The entire revenue village is one unit.

Source: Census, 2011b, p. 2

Table 2 gives an overview of percentage of rural and urban population while Table 3 gives the district-wise spread of rural and urban population in Uttarakhand.

Table 2: Percentage of rural and urban population

Percentage of Urban Population		Percentage of Rural Population	
2001	2011	2001	2011
25.6	30.5	74.33	69.45

Source: DoRD, GoI, 2011

Table 3: District-wise percentage of rural and urban households in Uttarakhand

District	% of Households in Rural Areas	% of Households in Urban Areas
Almora	91.48%	8.52%
Bageshwar	96.75%	3.25%
Chamoli	86.37%	13.63%
Champawat	88.44%	11.56%
Dehradun	51.06%	48.94%
Pauri Garhwal	88.37%	11.63%
Haridwar	69.37%	30.63%
Nainital	65.75%	34.25%
Pithoragarh	86.86%	13.14%
Rudraprayag	95.86%	4.14%
Tehri Garhwal	93.05%	6.95%
Udham Singh Nagar	70.13%	29.87%
Uttarkashi	92.61%	7.39%

Source: Socio-Economic and Caste Census, 2011 (DoRD, GoI, 2011)

The annual population growth in the state's hill districts was significantly lower than in the plains districts between 2001 and 2011 (0.70% in the hill districts as compared to 2.82% for the plains districts). Accordingly, the share of the population living in hill districts has declined from nearly 53% in 2001 to about 48% in 2011. Figure 5 shows that all ten hill districts recorded a decrease in the decadal population growth rate in 2011 compared to the 2001 Census, while the decadal population growth rate of the three plains districts had increased.

Population	1 Almora 622,506	2 Bageshwar 259,898	3 Chamoli 391,605	4 Rudraprayag 242,285	5 Pauri Garhwal 687,271	6 Tehri Garhwal 618,931	7 Pithoragarh 483,439
Change in decadal growth rate	135% ↓	55% ↓	58.6% ↓	51.37% ↓	136% ↓	85.5% ↓	58.17% ↓
Population	8 Uttarkashi 330.086	9 Champawat 259,648	10 Nainital 954,605	11 Haridwar 1,890,422	12 Dehradun 1,696,694	13 Udham Singh Nagar 1,648,902	
Change in decadal growth rate	48.46% ↓	11.1% ↓	23.2% ↓	6.7% ↑	29.32% ↑	0.4% ↑	

Figure 5: Change in decadal population growth rate between 1991–2001 and 2001–2011
Data Source: Census, 2011; Statistical Diary 2013–14, Uttarakhand State Government

The two hill districts of Almora and Pauri Garhwal recorded negative growth in population between 2001 and 2011. Together, the two districts saw an absolute decline of 17,868 persons over the decade (Mamgain and Reddy, 2016). While this may not seem so high, a decline in the total population is a rather unusual trend in India. Other hill districts in Uttarakhand have reported low population growth, among them Bageshwar, Chamoli, Pithoragarh, Rudraprayag, and Tehri Garhwal. Figure 6 shows the decadal change in population per district, based on Census figures from 1981, 1991, 2001, and 2011. A negative change in the population may reflect a population decrease due to several factors, such as high mortality, fewer births than deaths, or as a result of outmigration (or some combination of these). A number of studies have attributed the declining population in some of Uttarakhand's rural and hilly areas to outmigration (Department of Planning, GU, 2018; GU, 2018; Joshi, 2018; Mamgain and Suryanarayana, 2017; Pathak et al., 2017; Rural Development and Migration Commission, 2018). Joshi, in particular, attributes the high population growth in Uttarakhand's urban areas, as well as in the foothill regions, to increasing rural outmigration from the state's mountain and hill regions (Joshi, 2018, p. 4). Negative and low population growth in the state's hill districts merits further in-depth research.

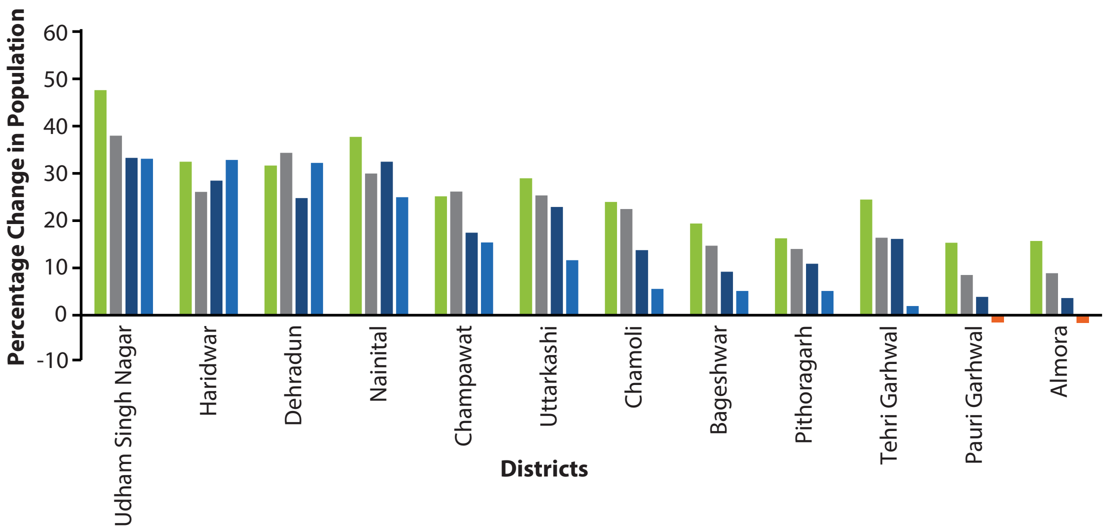


Figure 6: District-wise decadal change in population of Uttarakhand
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

2.2 Human Development Indicators

This section aims to discuss the different types of human development indicators in the state.

Human Development Index

The Human Development Index (HDI) is a tool used by the United Nations Development Programme (UNDP) to analyse a country's achievement in social and economic dimensions of development. The composite measure combines three key dimensions of human development: health, education, and standard of living.[12] The health dimension is assessed by life expectancy at birth; education is measured by the mean and expected years of schooling; and the proxy for the standard of living is the per capita income[13], adjusted for purchasing power parity.[14] The HDI is an integral part of UNDP's annual Human Development Report and allows to compare and track human development over time. A recent report by the Government of Uttarakhand uses the UNDP method to map current levels of socio-economic development in the relatively new state (GU, 2018). This section presents some of the results.

[12] The HDI is the geometric mean of these three dimensions. The precise method for the calculation of the HDI is described in the Technical Notes of the Human Development Report 2019: http://hdr.undp.org/sites/default/files/hdr2019_technical_notes.pdf.

[13] Per capita income is a measure of the mean income per person in a given area, for example a country or a district, in a specified year. In the HDI, it is based on the Gross National Income (GNI).

[14] The HDI is the geometric mean of these three dimensions. The precise method for the calculation of the HDI is described in the Technical Notes of the Human Development Report 2019: http://hdr.undp.org/sites/default/files/hdr2019_technical_notes.pdf.

The HDI in Uttarakhand increased from 0.531 in 2011–12 to 0.718 in 2017. The all-India HDI was 0.643 in 2017. Despite these overall positive trends, many challenges for human development remain, 'including climate change that impacts human development status via loss of life, livelihoods, environmental degradation and so on' (GU, 2018, p. 187). The report also lists 'regional inequalities and disparities between the hills and the plains districts' among the main challenges faced by the state (GU, 2018, p. 10).

Uttarakhand's hill districts have a lower HDI than the plains. Figure 7 shows that the three plains districts – Dehradun, Haridwar, and Udham Singh Nagar – have the highest HDI. These higher rankings mainly result from their higher per capita as the education and health indicators only show marginal differences with the hill districts. Unlike in the plains, the population of the hill districts mainly depends on subsistence-based agriculture for its livelihood. Moreover, the physical infrastructure such as roads, electricity, or a piped water supply is not well-developed in Uttarakhand's hill districts. These deficiencies reinforce the sharp dichotomy between the economic development of the hill districts and the plains districts. These gaps have cascading consequences as low levels of income hinder access to social infrastructure services such as education or health in the hill districts of Uttarakhand (Awasthi, 2010).

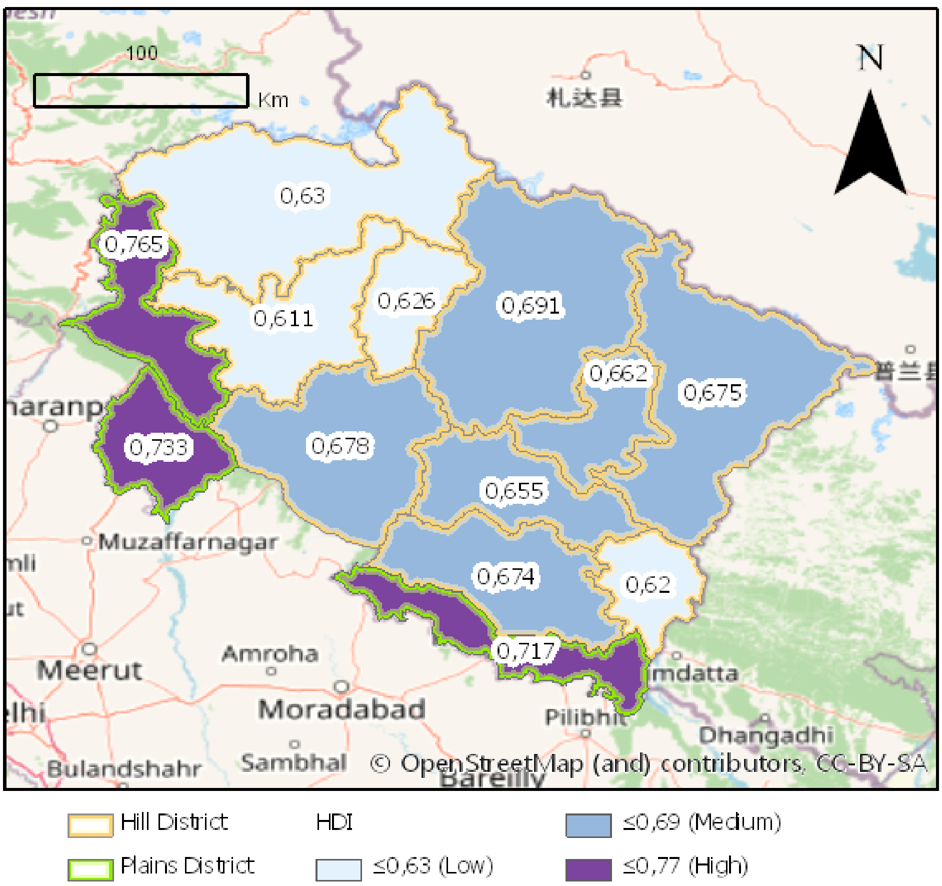


Figure 7: District-wise HDI
Source: GU, 2018a | **Image Credit:** Riccardo Biella, PIK

Health

Life expectancy at birth was 71.5 years in Uttarakhand in 2017 compared to the national average of 68.5 years. The HDI uses life expectancy as a measure to capture the health status of the population, as well as improvements in the health system over time. At 72.9 years, life expectancy in urban areas was slightly higher than the 71.0 years reported for rural areas, though this gap was smaller than the five-year difference at the national level: 72.2 years in urban areas versus 67.4 years in rural ones. Interestingly, life expectancy at birth in the three more prosperous plains districts (Dehradun, Haridwar, and Udham Singh Nagar) is lower than the state average (GU, 2018).

Education

HDI indicators for educational achievements are relatively good in Uttarakhand. The mean years of schooling in the state for people aged 25 or above is estimated to be 7.5 years. The HDR survey data shows that the hill district of Champawat, with a mean 6.3 years of schooling, has the lowest figure, and the plains district of Dehradun has the highest with 8.6 years (GU, 2018). The expected years of schooling, the second indicator in the HDI measuring educational achievements, is 11.2 years. On average, therefore, children beginning school in Uttarakhand complete their secondary level of education (GU, 2018). Other indicators for education help understand the full picture. The state's Net Enrolment Ratio (NER) is 89.18% at the primary level and 71.00% at the upper primary level. The school completion rate is 100% at the primary level and 96.76% at the upper primary level. For people aged seven years and above, the literacy level in Uttarakhand is 78.80%, which is higher than the national average of 74.00% (Census, 2011c). Districts in the hill region have a higher literacy rate than the plains districts (Planning Commission, GU, 2017, p. 176).

Standard of living and poverty

While Uttarakhand has experienced high levels of economic growth since state formation and per capita incomes have risen, around 11.3% of Uttarakhand's population lives below the poverty line (less than $1.25 a day), according to 2011–12 National Sample Survey data. The standard of living indicator in the Human Development Report of the Government is measured by per capita Net District Domestic Product (NDDP) of Rs. 157,400 (figures from the Department of Economics and Statistics for 2017-18). Since the per capita incomes and regional disparities are discussed in Section 2.3, this section focuses on poverty and other indicators. Uttarakhand has been able to bring down the poverty level in the past decade: the percentage of people living below the poverty line decreased from 31.8% in 2004–05 to 11.3% in 2011–12 (Planning Commission, GoI, 2013, 2007; Planning Commission, GU, 2017). This is about 10.0% less than the 21.9% living below the poverty line at the national level for the same year (Department of Planning, GU, 2018). The Development Report of the Government of Uttarakhand also sheds light on several other indicators critical for human development and well-being (GU, 2018). In Champawat and Pauri Garhwal, for instance, about one-third of all households do not have access to clean water source close to their home. In Uttarkashi, more than one-third of the household have no proper sanitation facility. Discussing regional disparities in development achievements between the hills and the plains, the report concludes that '[i]mproving income and health emerges as the most critical policy concern' (GU, 2018, p. 38).

Gender Development Index

Gender inequality remains one of the major barriers to progress in human development. In 1995, the UNDP created the Gender Development Index (GDI) to measure gaps in human development between women and men, using the same indicators as in the HDI (UNDP, n.d.). The closer the GDI is to 1.0, the smaller is the gap between the human development of women and men.[15] *The Human Development Report of the Government of Uttarakhand* lists GDI values at the state and district levels, and emphasises that the GDI is a helpful tool 'for advocacy and policy formulations to address inequalities and for re-prioritizing resource allocations' (GU, 2018, p. 26). In 2017, the state-wide GDI was 0.727, compared to 0.841 at the national level (UNDP, 2018).

GDI values in Uttarakhand range from 0.892 in Uttarkashi to 0.561 in Haridwar. The district with the highest GDI, Uttarkashi (0.892), is followed by other hill districts, namely Rudraprayag (0.864), Bageshwar (0.820), Pauri Garhwal (0.791), Champawat (0.757), Pithoragarh (0.728), Tehri Garhwal (0.726), Almora (0.721), Chamoli (0.698), and Nainital (0.679). With Udham Singh Nagar (0.632), Dehradun (0.593) and Haridwar (0.561); the three plains districts can be found at the bottom of the district-wise GDI ranking (Figure 8).

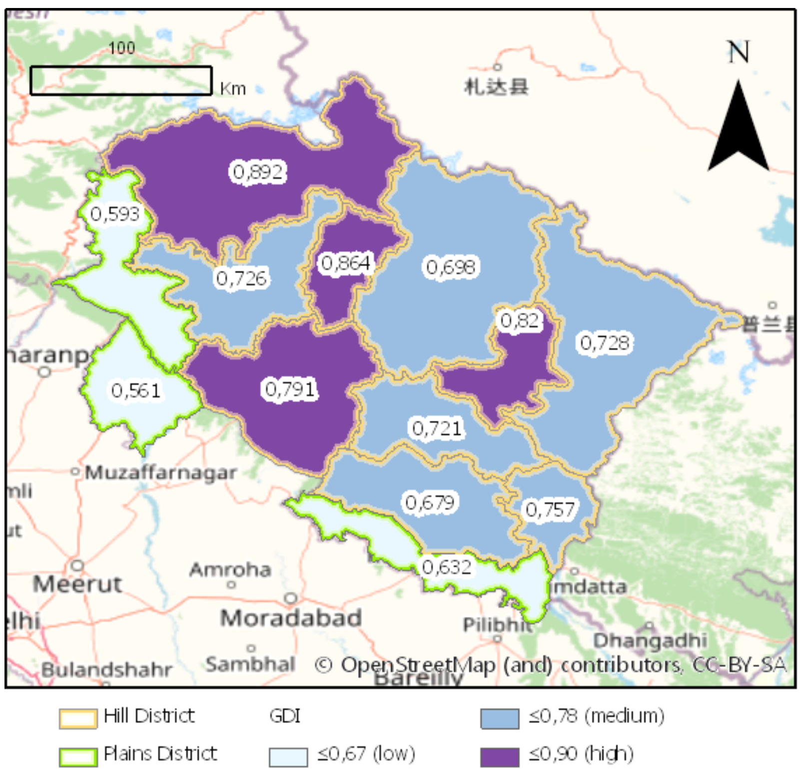


Figure 8: District-wise GDI of Uttarakhand, HDI Report
Source: GU, 2018a | **Image Credit:** Riccardo Biella, PIK

[15] To get the GDI value, the HDI is first calculated separately for women and men. The ratio of these gender-specific HDIs is the GDI. The closer this ratio is to 1, the smaller is the gender gap [United Nations Development Programme (UNDP), 2019]. For a detailed account of the method, refer to the Technical Notes of the Human Development Report 2019: http://hdr.undp.org/sites/default/files/hdr2019_technical_notes.pdf.

In contrast to the HDI, thus, hill districts outrank plains districts in the GDI. Generally, higher GDI values in hill districts indicate that the inequality between women and men is lower in the hill districts as compared to plains districts. The differences between the rankings of hill districts and plains districts in the HDI and the GDI, however, do not only shed light on gender relations. A closer look at per-capita incomes helps explain this. Though considerable gender gaps in per capita income persist in all districts of Uttarakhand, the gap is smaller in hill districts due to the overall worse economic situation in the hills. As depicted in Figure 9, men in hill districts earn considerably less when compared to their male counterparts in the plains districts of Dehradun, Haridwar, and Udham Sing Nagar. The gender gap in annual per capita income, thus, is smaller per se in the hill districts. Nevertheless, women in hill districts do have a slightly higher per capita income as women in plains districts.

Higher participation of women in income-generating activities in the hills may be attributed to male outmigration. A study by Mamgain and Reddy found that the share of working males in Uttarakhand is smaller in the hill districts than the plains districts (2016). The authors conclude that 'low rate of workforce participation among males is not a demographic phenomenon; instead it is purely an economic phenomenon where a large percentage of the males out-migrate for earning cash income […] and females replace their labour, thereby increasing their overall participation' (Mamgain and Reddy, 2016, p. 28). Therefore, although male outmigration from the hills creates income-earning opportunities for the women who remain, it also increases their responsibilities for agricultural activties. Understanding the full implications of these changes – on women, gender relations, and gender-based social norms – will require more research, which could help inform policies to address the gap between male and female development in the state.

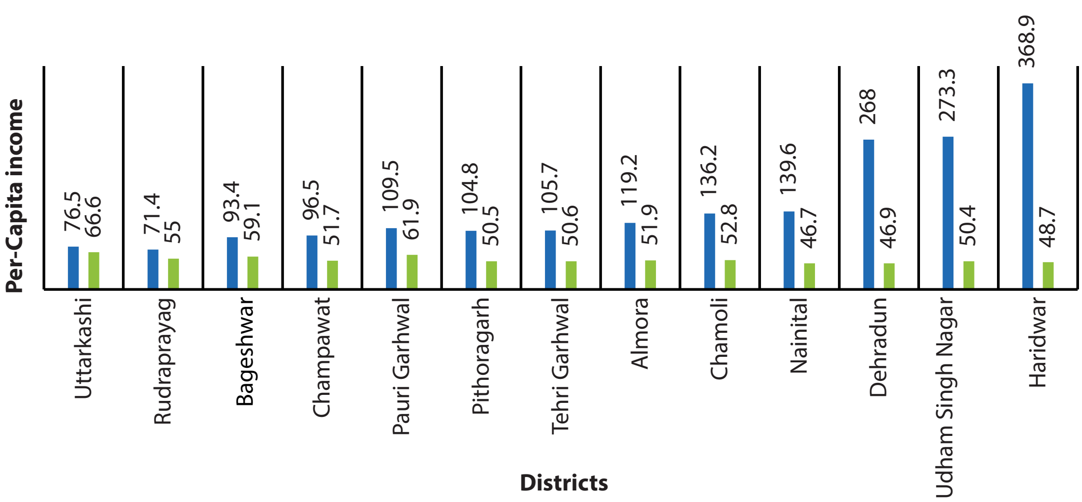


Figure 9: District-wise GDI of Uttarakhand, HDI Report
Source: GU, 2018a | **Image Credit:** Riccardo Biella, PIK

2.3 Economic Growth and Regional Disparities

In the years following its formation, Uttarakhand has witnessed rapid economic growth. The increase in the state's Gross State Domestic Product (GSDP[16]) was 9% on average between 2001–2002 to 2011–2012 (at 2004–2005 prices) (Planning Commission, GU, 2017). The real per capita income in this period increased approximately 4.5 times (from Rs. 19,164 to Rs. 92,911). When compared to the national average, the per capita income in Uttarakhand has been higher from 2005–2006 onwards. As Figure 10 shows, Uttarakhand has also performed better than its neighbouring hill state of Himachal Pradesh since 2008–2009. Most remarkable, though, may be the increase in the state's per capita income when compared with its parent state Uttar Pradesh (UP). Fifteen years after the separation, per capita income in Uttarakhand was more than three times that of UP (Mamgain and Reddy, 2016) even though both states had similar figures in 2001–2001. In 2016–2017, the average per capita income in Uttarakhand was 160,796 (in INR) or approximately 2500 (in USD).

However, regional disparities in district-wise per capita incomes indicate that not all regions have benefitted equally from the state's economic success. As discussed before, per capita incomes in Uttarakhand's plains districts are higher than per capita incomes in the hill districts. Figure 11 shows how in 2016–17, the three plains districts have per capita incomes above the state's average of 160,796 (in INR) or 2500 (in USD) while the hill districts are all below that level. Moreover, the per capita income of some hill districts (Bageshwar, Champawat, Tehri Garhwal, and Almora) is almost half of that of the plains districts of Dehradun and Haridwar (Rural Development and

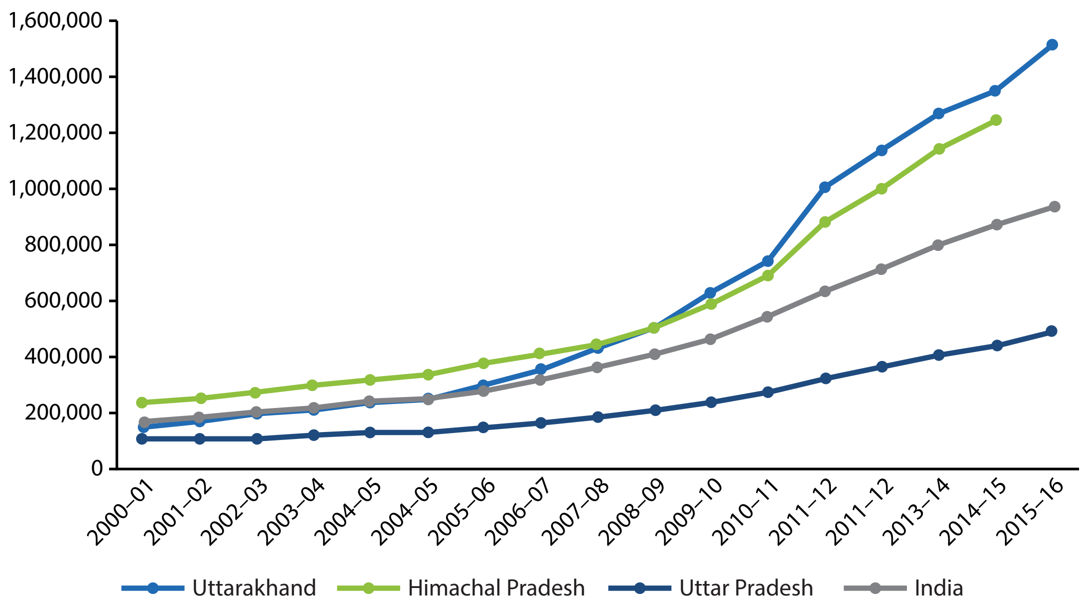


Figure 10: Per capita gross state domestic product of Uttarakhand compared to the national average, Himachal Pradesh, Uttar Pradesh. For years 2000–2001 to 2004–2005, at 1999–2000 prices; for the period 2004–2005 to 2011–2012, at 2004–2005 prices
Source: Mamgain and Suryanarayana, 2017

[16] The Gross State Domestic Product (GSDP) can be defined as 'a measure, in monetary terms, of the volume of all goods and services produced within the boundaries of the State during a given period of time, accounted without duplication. Data describes the average annual growth rates in GSDP at Current Prices'. Source: https://data.gov.in/keywords/gross-state-domestic-product.

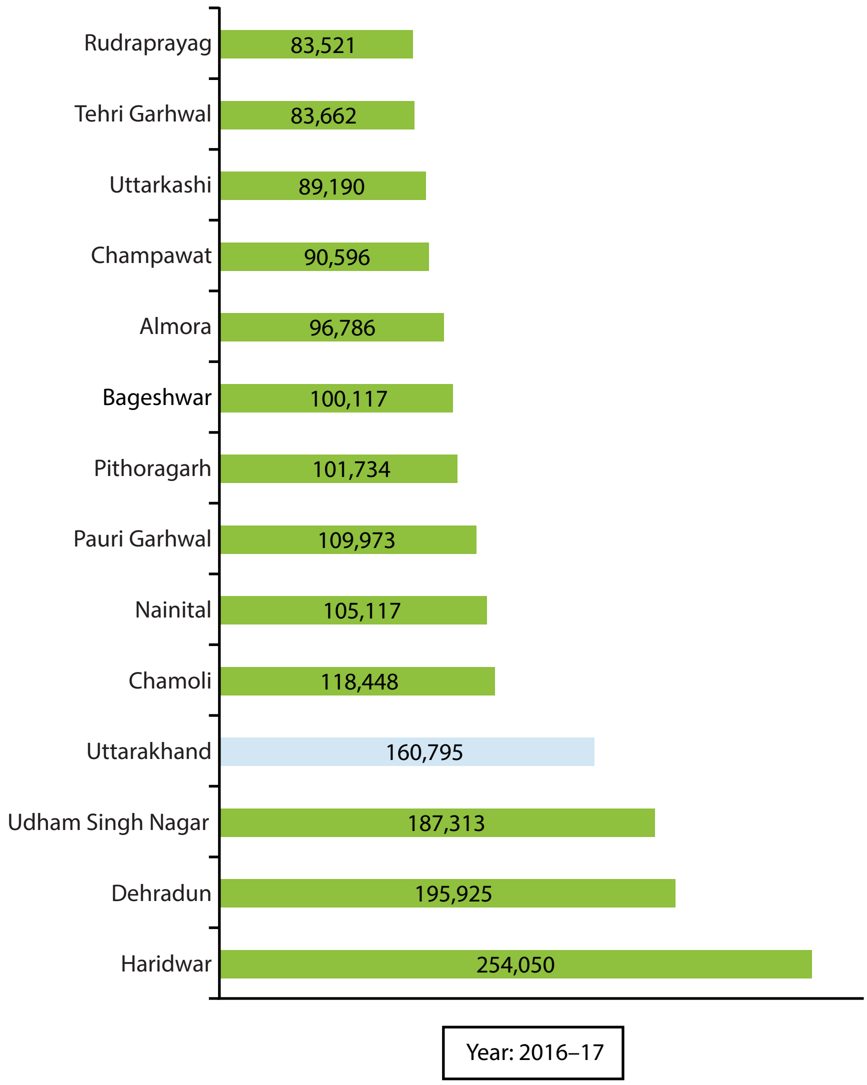


Figure 11: District-wise per capita income for the year 2016–17
Source: Planning Commission, Government of Uttarakhand 2017

Migration Commission, 2018). The disparities in district-wise per capita incomes (measured in terms of per capita net district domestic product) are an indicator of inequality in the state, linked to economic development planning and public investments that primarily stimulated economic growth in the plains.

The characteristics of Uttarakhand's industrialisation process have led to structural regional inequalities. On a path of rapid industrialisation, 16,012 new industrial units were set up in the state by March 2010, while the corresponding figures for the neighbouring hill state of Himachal Pradesh (HP) were 7,606 units (Planning Commission, GU, 2017). While public investment was major reason behind this development (Planning Commission, GU, 2017), the strategy increased regional disparities as a result of uneven investments. The majority of SIDCULs[17] (State Industrial Development Corporation of Uttarakhand Limited), for instance, which essentially promote industries and develop industrial infrastructure in the State, are located in plains districts (SIDCUL, 2015). Today, most of the activities in the secondary and tertiary sectors of the economy are clustered in the plains districts (see Box 2 on sectors of the economy). Since almost all the growth in the state's economy has been in these sectors, the hill districts had, and continue to have, competitive disadvantages.

Box 2: Sectors of the Economy

The economy is divided between three sectors – primary, secondary, and tertiary

1. Primary sector includes crops, livestock, fishing, forestry & logging, and mining & quarrying
2. Secondary sector includes manufacturing, electricity, gas, construction, and water supply & other utility services
3. Tertiary Sector includes transport, storage, trade, repair, hotel & restaurants, financial services, real estate, communication & services related to broadcasting, and other services.

Source: *Planning Commission, GU 2017*

As a result of uneven investments and the changing face of the economy, hill districts have become detached from the development process. Disaggregated time-series data of the gross state domestic product (GSDP) shows a rapidly changing structure of the state economy (Figure 12). In the two decades from 1993–94 to 2012–13, the share of the primary sector in Uttarakhand's GSDP has declined from about 40% to about 11% (Dhyani, 2015). In absolute terms, real growth in the primary sector was 22.5% between 2004 and 2013. The corresponding figures

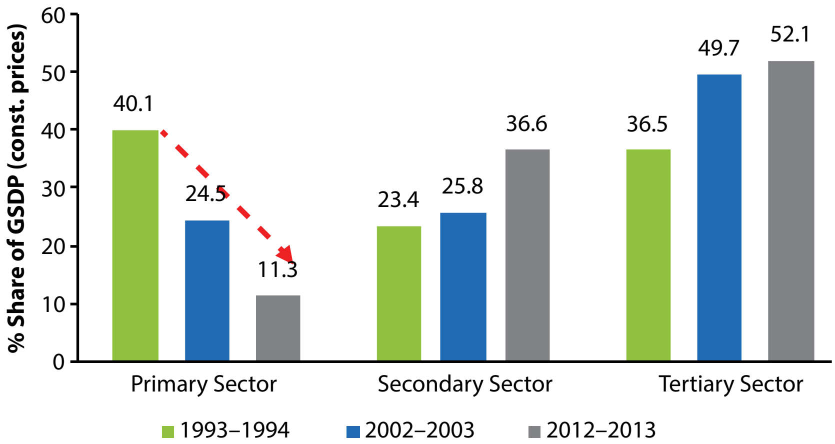


Figure 12: Sector wise share of gross state domestic product (GSDP)
Source: 1993–94: Trends in Agriculture & Agricultural Practices in Ganga Basin, Part 1: Uttarakhand. 2004-05 and 2012–13.
Source: Directorate of Economics & Statistics, 2013;
Figure Credit: Himani Upadhyay, PIK

[17] SIDCUL is a Government of Uttarakhand enterprise founded in 2002 with the main aim 'of providing overall industrial development of the state by developing necessary infrastructure and industrial in the state of Uttarakhand directly or through special purpose vehicles, investments assisted companies etc'. Source: https://www.siidcul.com/about/siidcul. The link also provides the list of SIDCULs, and most of them are located in the plains.

for the secondary and the tertiary sectors are 245% and 168%, respectively.[18] Since the plains districts became the hub of economic activity after state formation, as discussed above, hill districts could not benefit equally from the growth in the secondary and tertiary sectors of the economy. The result has been an increased disparity between plains and hill districts and increased migration flows (Department of Planning, GU, 2018).

Despite the declining importance of the primary sector for Uttarakhand's GSDP, it still employs almost 70% of the state's population (Chopra, 2014; Planning Commission, GU, 2017, p. 51), (see Figures 12 and 13[19]). The population remains strongly dependent on agriculture and related sectors, rendering them vulnerable to climate-induced changes in agriculture (see Section 3.5 Climate Change Vulnerability Profile of Uttarakhand's Districts). The challenges for agriculture in the state's hill districts are manifold, though, including changing aspirations of young people who seek employment outside the primary sector (see also Section 4.3 Reasons for Migration). With the majority of the population depending on rain-fed and subsistence-based agriculture, the adverse effects of climate change on agricultural productivity in Uttarakhand are crucial in understanding migration dynamics in the state (see Section 5.2 Climate Change, Agriculture and Migration). In Vision 2013, the Government of Uttarakhand sets out its strategy to reduce migration, including the aim to 'transform agriculture through diversification towards horticulture, aromatic and medicinal plants, animal husbandry, etc. to make agriculture profitable and retain people in the hills by giving additional employment opportunities' (Department of Planning, GU, 2018) (see Section 6 for a summary of this and other policies).

The development gains from the economic progress have not been equally distributed across the state. As discussed in this section, uneven public investments and the changing face of the economy put hill economies at a disadvantage. Most of the population in hill areas depend on subsistence-based and rain-fed agriculture often on fragmented land with low productivity. Furthermore, connectivity and poor access to infrastructure, technology,

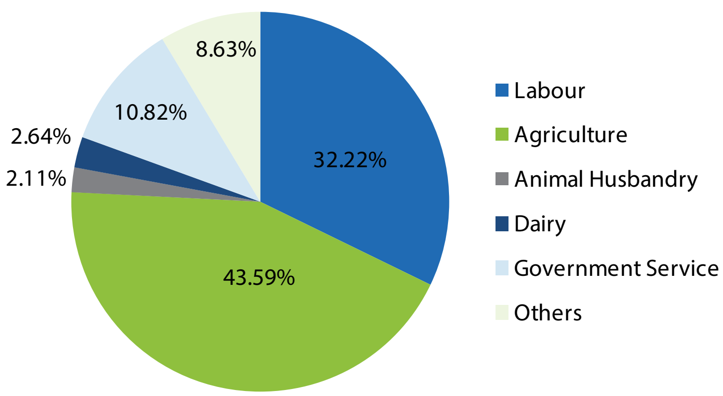


Figure 13: Main occupations in Uttarakhand
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

[18] In the secondary sector, construction and manufacturing have been among the fastest growing subsectors. Trade, hotel and restaurant, catering, tourism, hospitality industry and transport were primarily contributing to the growth in the tertiary sector. Unlike the national pattern of growth, the IT sector has not played a major role in the economic growth of the state. It is rather trade, transport and tourism that dominate (Planning Commission, GU, 2017).

[19] The term 'labour' in the pie chart (Figure 11) refers to those persons engaged in irregular work, compensated on a daily basis.

information and markets add to the vulnerabilities of populations who live in the hill districts (GU, 2018). The main centres of urbanisation and population growth have been cities and towns in the plains. The most recent census locates all the designated urban agglomerations in the plains (Dehradun, Roorkee, Rudrapur, Haldwani, Haridwar, Rishikesh, and Kashipur) and reports an urbanisation rate for the state at 30.55% (Census, 2011, 2011b). Accompanying the twin process of urbanisation and population growth has been the exodus from hill villages into towns and cities in the plains, leading to so-called 'ghost villages', which, if it were not for the elderly, would be uninhabited (Dey, 2017; Press Trust of India, 2018; Upadhyay, 2018).

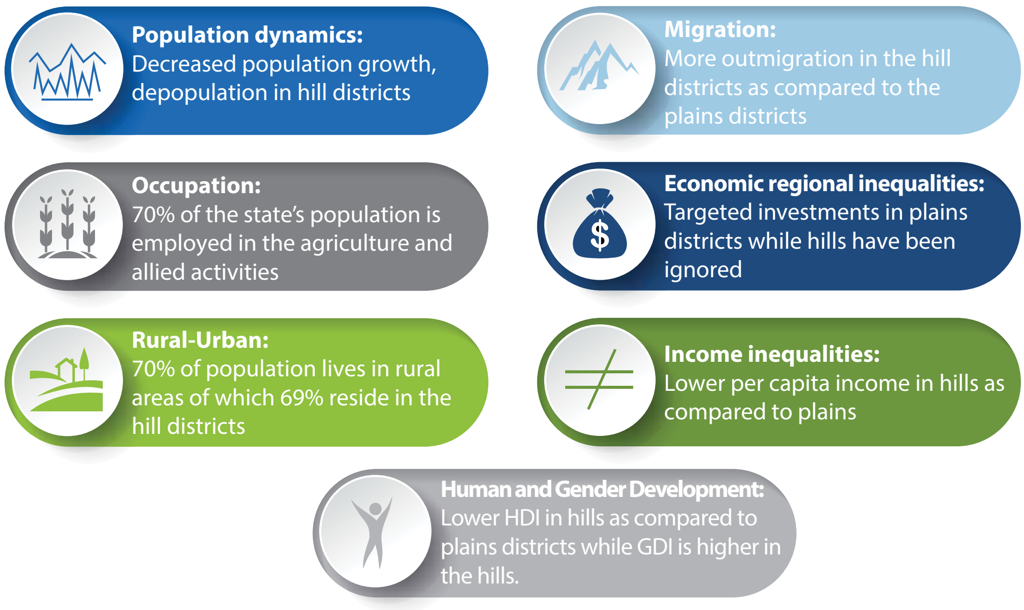
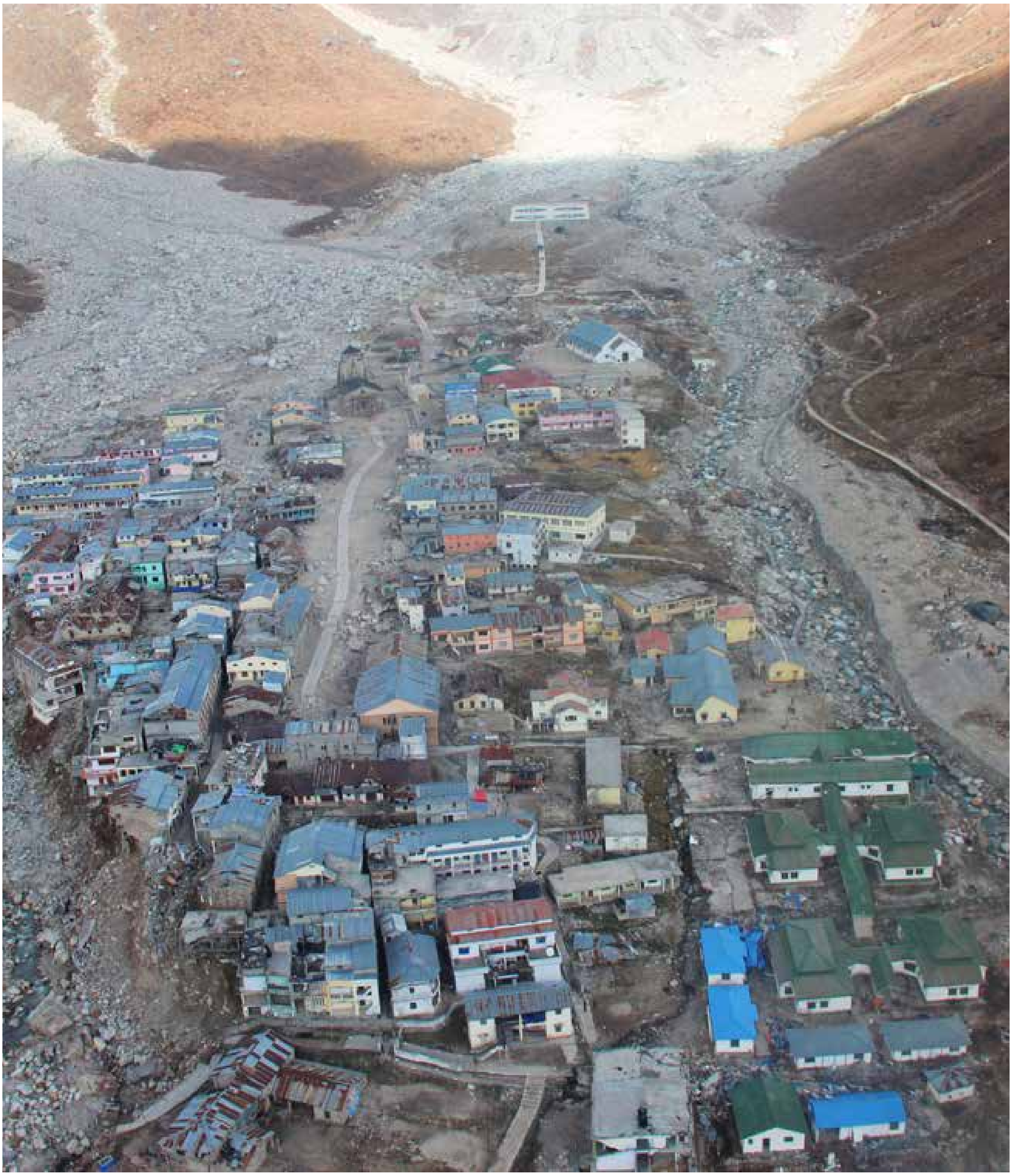


Figure 14: Summary of Section 2
Figure Credit: Himani Upadhyay, PIK

OBSERVED AND PROJECTED CLIMATE CHANGE IN UTTARAKHAND



Uttarakhand. Still recovering from 2103 floods.

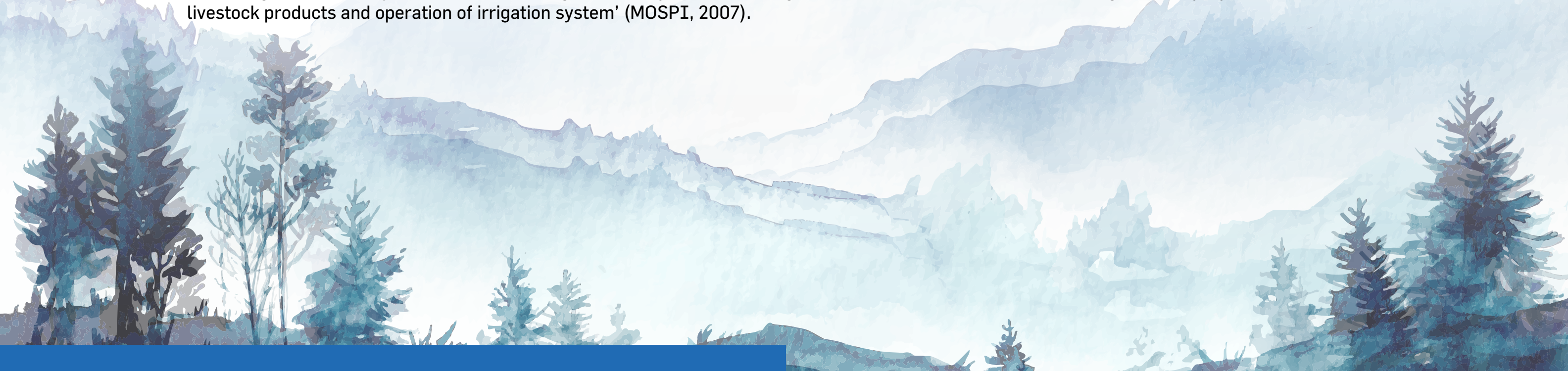
3 Observed and Projected Climate Change in Uttarakhand

Uttarakhand's varied geography is highly exposed to several climate-related changes. Mountain regions experience elevation dependent warming (EDW) where the rate of warming is amplified at a higher elevations, i.e. they experience more rapid and acute changes in the temperature than at the lower elevation regions (Pepin et al., 2015). This can lead to changes in the snow line where mountain elevations that were earlier covered with snow may become snow-free (Kohler et al., 2009). According to the Hindu Kush Himalaya Assessment, the Himalayan glaciers could lose one-third of their ice by the end of the century if global average temperatures exceed 1.5 °C above their pre-industrial level (Wester et al., 2019). Another study based on forty years of satellite data assessed the ice thickness during the time intervals of 1975–2000 and 2000–2016 across a 2000 km Himalayan transect. It found that the average loss of ice had doubled during 2000–2016 period as compared to 1975–2000 (Maurer et al., 2019). According to H.D. Pritchard, in high-mountain Asia, 'shrinking store of ice will lead initially to increased glacier runoff volumes, [...] peaking around the year 2030 under IPCC climate scenario RCP 2.6 or about one to three decades later under scenario RCP8.5' (Pritchard, 2019, p. 654). In the short-term, this could lead to floods in the region, while in the long-term, the loss of glacial ice would result in reduced water availability. Water scarcity has severe consequences for the local mountain communities and could contribute to decline in agricultural yields in the region (IPCC, 2019, p. 15; Rasul et al., 2019). Climate change can also have adverse impacts on mountain aesthetics[20] and local cultures practices, with implications for migration (IPCC, 2019).

In Uttarakhand, scientific studies have noted changes in precipitation and temperature likely to affect the discharge, volume, and availability of water (Bandyopadhyay and Perveen, 2003; Kumar et al., 2006; Negi et al., 2012; Viviroli et al., 2007, 2003). Changing climatic conditions would also lead to more frequent droughts coupled with an increased incidence of high-intensity rainfall (GU, 2014; Krishnan et al., 2019; Pandey and Mishra, 2015; Tewari et al., 2017). According to a report released by the Government of India in 2018, the country is already experiencing the worst water crisis in its history with 600 million people facing extreme water stress, of whom approximately 200,000 die every year due to inadequate access to safe drinking water. By 2030, the estimated demand for water will be twice as a high as the available supply, a concerning outcome in a country already strained by water crisis (NITI Aayog, 2018, p. 15). These trends could have cumulative impacts on migration, as 70% of Uttarakhand's population is employed in agriculture or related activities[21]. So any meaningful change in temperature and rainfall patterns directly affect the livelihoods of its people (Planning Commission, GU, 2017, p. 51).

[20] Mountain aesthetics refer to 'cryosphere's aesthetic value, which promotes cryospheric tourism. The aesthetic value mainly refers to the cryosphere landscape's artistic characteristics (e.g., shape and colour), status and significance (e.g., diversity, oddity, pleasure, and integrity). With its distinct monopoly on aesthetic value, the cryosphere landscape cannot be copied. The cryosphere contains many different elements including glaciers, glacier relics, ice sheets, ice shelves, sea ice, snow cover, frost, frost heave, snow cover, freezing rain, freezing fog, ice sculptures, and other related aesthetic and cultural characteristics, which are important tourist attractions and play significant roles in recreational service' (Hock et al., 2019, p. 171; Xiao et al., 2015, p. 184).

[21] According to the Ministry of Statistics and Programme Implementation, agriculture and allied activities include 'agriculture proper, livestock and livestock products and operation of irrigation system' (MOSPI, 2007).



Representation Concentration Pathways

A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5). Four pathways, namely RCP 2.6, RCP4.5, RCP 6, and RCP8.5 describe different climate futures and together span the range of year 2100 radiative forcing values, i.e. from 2.6 to 8.5 W/m^2 are named after a possible range of radiative forcing values. To assess future changes in climate, this report employs RCP4.5 and RCP8.5 scenarios. RCP8.5 basically provides the trajectory if we continue with our current level of emissions without any effective mitigation measures whereas the other future pathway regime RCP4.5 shows a lesser warming potential for future. Hence, this assessment tries to provide information on how the future climate would evolve over the state under these two representative scenarios. An overview of these two scenarios are shown in Table 4 (van Vuuren et al., 2011).

Table 4: Overview of representation concentration pathways

Pathway	Description	IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100	(Riahi et al. 2007)—MESSAGE
RCP4.5	Stabilisation without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100	(Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009)—GCAM

This section analyses historical trends in temperature and precipitation (sub-section 3.1) and presents climate projections under different climate change warming scenarios of RCP4.5 and RCP8.5 (Section 3.2.), with a particular focus on the analysis of monsoon trends (Section 3.3). Thereafter, an overview of the past extreme weather events, followed by future projections of climate extremes are discussed (Section 3.4). This section draws on climate change observations and projections, and concludes with a discussion on a district-wise vulnerability profile for the state (Section 3.5) and its plausible links to migration.

3.1 Observed Climate Variability

Observed Temperature

Temperatures in Uttarakhand are rising. Two studies conducted by Mishra and Yadav report a notable warming trend for the Uttarakhand region from 1911 to 2011, as shown in Figure 15. On average, the annual temperature increased by 0.46 °C. This warming has accelerated in the last decade. Temperatures in hill districts, such as Uttarkashi, Chamoli, Rudraprayag, and Pithoragarh, increased more substantially, while in Haridwar, Dehradun, and Pauri Garhwal increases were smaller as compared to others (Mishra, 2017; Yadav et al. 2014).

Many studies have been carried out which have analysed the temperature trends annually as well as seasonally over the state. In most of the climate scale studies, temperature is analysed with respect to changes in its maximum (highest temperature recorded in a day) and minimum (lowest temperature recorded in a day) values. Pranuthi and INRM report that, between 1950 and 2013, Uttarakhand's annual average maximum temperature shows a decreasing or cooling trend, while the state's minimum temperature shows an increasing or warming trend for all of its thirteen districts. Although the annual trends are not statistically significant[22], seasonal trend analysis reveals high variations, meaning the changes with respect to seasons need deeper analysis. Table 5 summarises the changes in monthly mean temperature between 1911 and 2011. It shows that the winter months of November, December, and February have recorded the maximum rise in temperature, whereas the monsoon months of June, July, August, and September have shown a cooling trend (Pranuthi et al. 2014; INRM, 2016b).

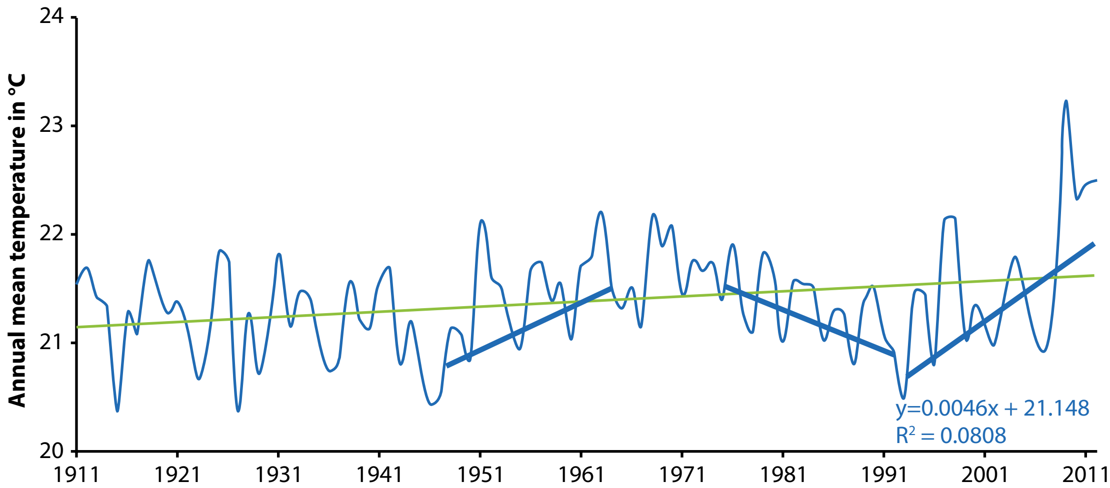


Figure 15: Annual mean temperature trend of Uttarakhand (1911–2012)

Table 5: Monthly mean temperature changes (°C/100 Year)

District/State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Almora	0.49	1.77**	1.12	0.75	0.09	-0.43	-0.27	-0.36*	-0.21	0.29	1.00**	1.27**
Bageshwar	0.63	1.79**	1.19	0.8	0.14	-0.36	-0.2	-0.31	-0.18	0.35	1.01**	1.32**
Chamoli	0.73	1.73**	1.25*	0.87	0.23	-0.27	-0.22	-0.24	-0.17	0.37	1.00**	1.24**
Champawat	0.54	1.77**	1.07	0.71	0.14	-0.38	-0.17	-0.31	-0.18	0.33	0.99**	1.32**
Dehradun	0.56	1.47**	1.07*	1.15*	0.46	-0.5	-0.58*	-0.50*	-0.44*	-0.09	0.87**	0.97**
Pauri Garhwal	0.54	1.63**	1.05	0.92	0.21	-0.47	-0.45	-0.43*	-0.33	0.16	0.93**	1.14**
Haridwar	0.55	1.50**	0.9	1.12*	0.3	-0.55	-0.63*	-0.51*	-0.48*	-0.07	0.87**	1.11**
Nainital	0.44	1.75**	1.03	0.72	0.06	-0.49	-0.29	-0.35*	-0.24	0.28	1.05**	1.32**

22 Statistically significant implies that under a given time period, increase in temperature is statistically large to be given due consideration in policy planning. However, it may be noted that the year-to-year variations is a part of this increasing trend for the full time period. Hence, it becomes very important to understand the intra year– intra seasonal variations of temperature within this long-term rise in temperature.

District/State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pithoragarh	0.78	1.82**	1.24*	0.87	0.21	-0.26	-0.1	-0.25	-0.13	0.39	1.02**	1.36**
Rudraprayag	0.72	1.71**	1.23*	0.89	0.28	-0.27	-0.28	-0.24	-0.2	0.34	0.98**	1.16**
Tehri Garhwal	0.6	1.54**	1.16*	1.01	0.36	-0.4	-0.42	-0.38	-0.31	0.13	0.90**	0.99**
Udham Singh Nagar	0.44	1.70**	0.99	0.76	0.08	-0.57	-0.36	-0.35*	-0.3	0.27	1.10**	1.31**
Uttarkashi	0.67	1.58**	1.29*	1.02*	0.46	-0.28	-0.33	-0.27	-0.22	0.2	0.98**	1.06**
Uttarakhand	0.59	1.67**	1.12	0.89	0.23	-0.4	-0.33	-0.35*	-0.26	0.23	0.98**	1.20**

**Trend is significant at a 99% confidence level.
* Trend is significant at a 95% confidence level.
Source: Mishra, 2017

Uttarakhand's annual minimum temperature increased by 0.42 °C over sixty three years from 1951 to 2013, during which time the annual maximum temperature decreased by 0.25 °C. Neither trend is statistically significant (INRM, 2016a). Over that same period, however, the winter season (viz. the months of January and February), shows a statistically significant decreasing trend for maximum temperature for all the districts in the state, while minimum temperature shows a statistically significant increasing trend for the districts of Uttarkashi, Dehradun, Tehri Garhwal, and Pithoragarh.

Observed rainfall

Rainfall variability is an important indicator of changing regional climate. Large rainfall variations may lead to extreme events of either droughts or floods which affect both life and property. Many studies have investigated the variability and trends of rainfall in the state of Uttarakhand and its districts both temporally and spatially (Mishra, 2017, 2014; Pranuthi et al., 2014; Yadav et al., 2014). Mishra (2017) analysed the rainfall pattern during the 1911 to 2011 period (Figure 16) showing a notable inter-annual variability in the rainfall pattern over the last 100 years in the analysed dataset and a more prominent decreasing trend after the 1990s. Although there is not much reduction in total annual rainfall is seen after the 1990s, it may put great stress on the water resources of the region. As seen in Figures 17 and 18 the decline in rainfall is not uniform throughout the state. Haridwar is the only district which has witnessed a slight increase in rainfall while all other districts are in rainfall-deficit. This rainfall shortage is more acute in the hill districts, such as Pithoragarh, Bageshwar, Almora, Champawat, and Nainital (Mishra, 2014). The hilly regions of the state have become drier, and rainfall is declining from south to north and from west to east (Mishra, 2017). The variation of annual rainfall across the districts of Uttarakhand has been between 20%–36% a year from 1951 to 2013 (INRM, 2016a).

Figure 17 shows the monthly rainfall changes from 1911 to 2011 over different districts of Uttarakhand. It shows a trend of decreasing rainfall in all months except for March, May, and November. Strong decreasing trends are also shown for the monsoon season. This considerable change in rainfall patterns will have significant impacts on agriculture and cropping yields since about 80% of the agriculture in the state is rain-fed (Mishra and Chaudhuri, 2015).

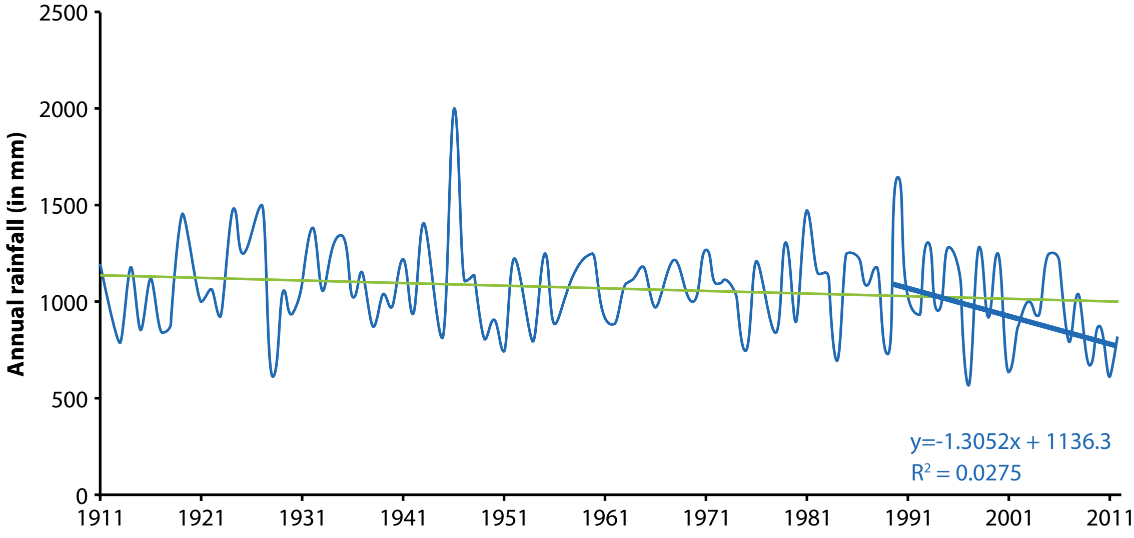


Figure 16: Annual rainfall trend of Uttarakhand
Source: Mishra, 2017

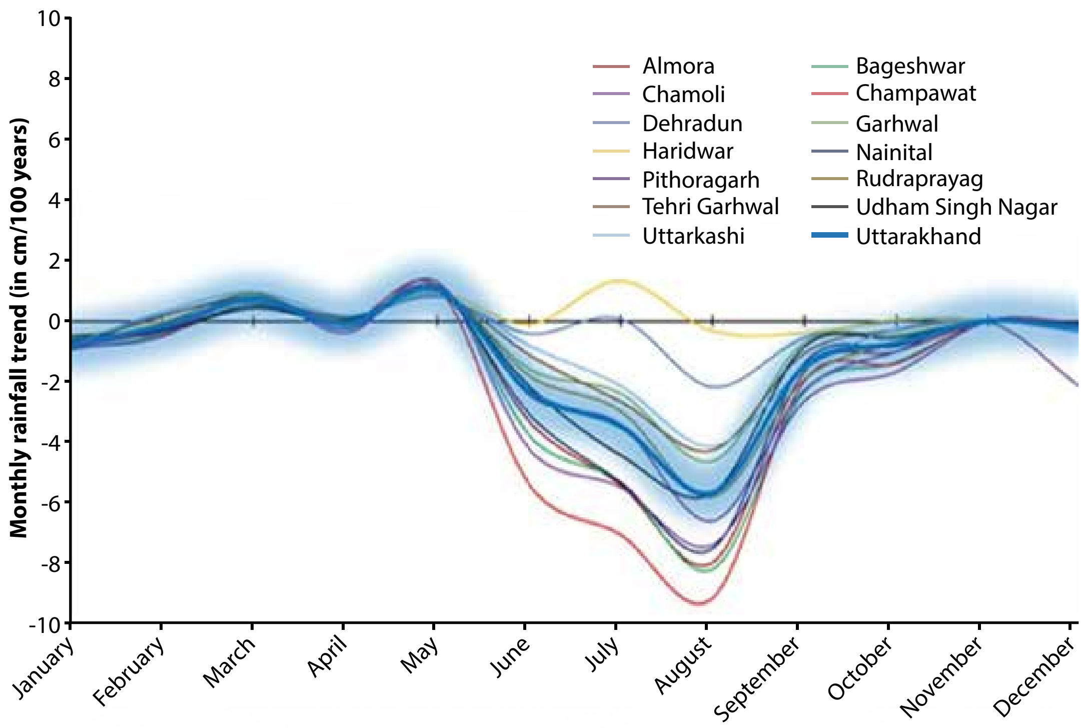


Figure 17: Monthly rainfall changes during 1911–2011
Source: Mishra, 2017

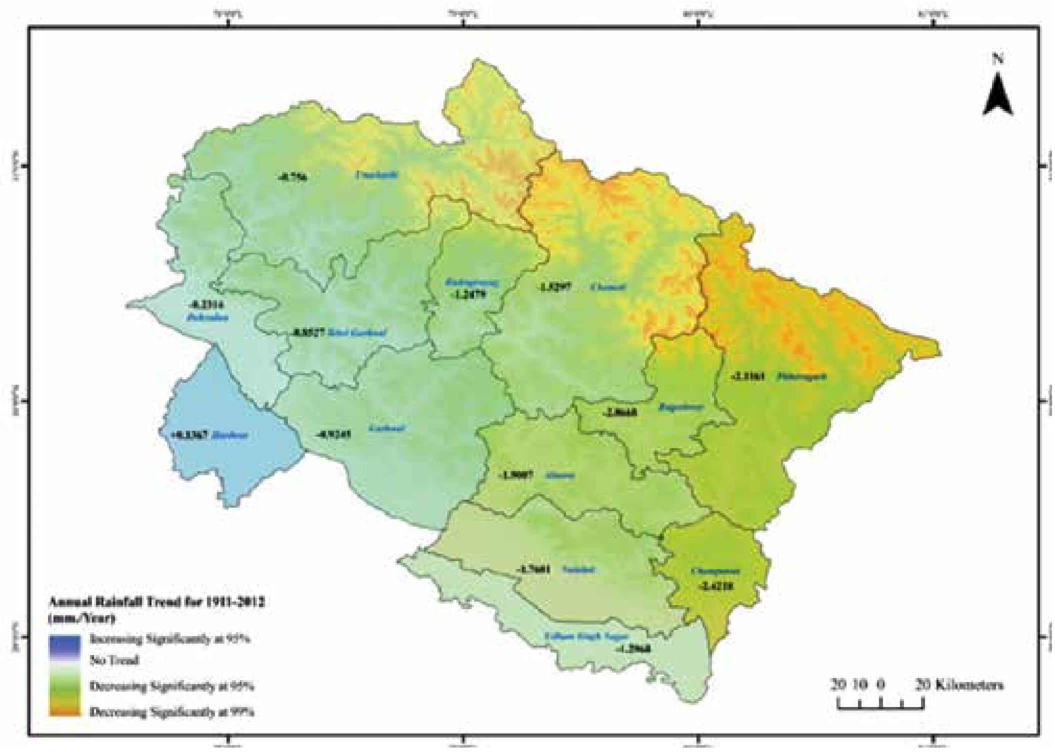


Figure 18: Spatial distribution of annual rainfall changes
Source: Mishra, 2017

Annual rainy days have also decreased from 1951 to 2013 across Uttarakhand (INRM, 2016a) as depicted in Figure 19. Although the negative trend for annual rainfall is statistically not significant, the negative trend for rainy days is statistically significant. Therefore, although the number of rainy days has fallen, the cumulative yearly rainfall has not substantially decreased – indicating an increasing intensity of rainfall from 1951 to 2013 for the state.

3.2 Future Climate Outlook

Changing the future climate may place additional stresses on ecological and socio-economic systems that already face tremendous pressures from rapid urbanisation, industrialisation and, in general, economic developments. Climate science thus seeks to predict future trends by incorporating these potential stresses and impacts to help inform policymaking at global, regional, and local scales. Different global and regional climate models are used by the climate science community to help decision-makers understand and act upon the projections of future climate and its impacts. The Intergovernmental Panel on Climate Change (IPCC) in its 5th Assessment Report (AR5) mentioned that the global surface temperatures had shown an increasing (warming) trend of 0.85 °C for the period of 1880 to 2012 (IPCC, 2014). Under a non-uniform and dynamic climate change scenario, understanding the regional climate variations is also of utmost importance.

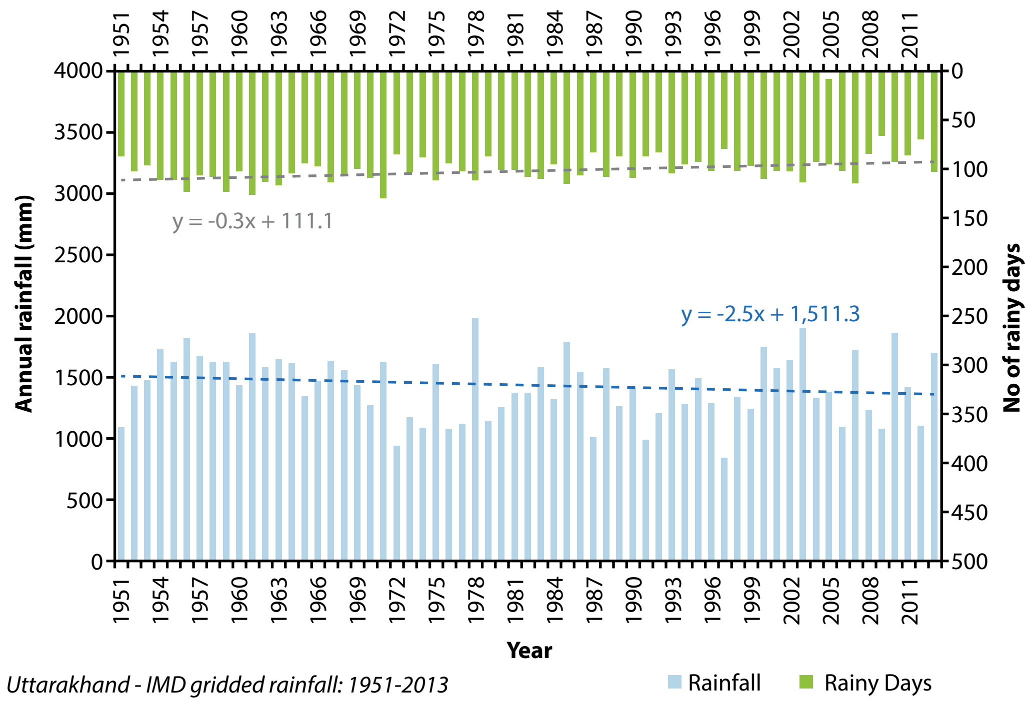


Figure 19: Characteristics of observed annual rainfall and number of rainy days of Uttarakhand (1951 – 2013)
Source: INRM, 2016b

Climate change projections for India under existing trends –RCP6.0 to RCP8.5–mean a likely warming of 1.7 °C to 2.0 °C by the 2030s (between 2021 and 2050), and of 3.3 °C to 4.8 °C by the 2080s (between 2070 and 2099), relative to preindustrial times. Under this scenario, precipitation is projected to increase from 4% to 5% by the 2030s, and from 6% to 14% by the 2080s, compared to the 1961 to 1990 baseline (Chaturvedi et al., 2012). Projections for the Indian Himalayan region also point towards considerable warming. It has been reported that the maximum temperature has been varying from 0.3 °C to 1.0 °C per decade and minimum temperature has been varying from 0.3 °C to 1.1 °C per decade under the extreme RCP8.5 scenario (Dimri et al., 2018).

This report uses high spatial resolution data to analyse climate impacts in the state of Uttarakhand, by capturing topography and regional climate variability lost at a lower resolution, especially in mountainous regions (Hijmans et al., 2005). High-resolution, bias-corrected NEX-GDDP data, with a spatial resolution of 25km × 25km, is used (as detailed in the next section). The results in this study are also in line with other state-wide assessments like INRM (2016a).

This section provides the information on future changes of climate parameters specifically temperature and rainfall with respect to their general averages over the area as well as their extreme behaviour. To understand the future changes, two competing RCPs have been used mainly RCP4.5 and RCP8.5.

Data used and methodology

NASA's Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset was used to analyse the projected changes for the near-future (2021–2050), mid-future (2051–2080), and far-future (2081–2099) periods – in terms of rainfall, maximum and minimum temperature, and various extreme climate indices – and map them for the state of Uttarakhand and its districts. NEX-GDDP applies statistical techniques of creating granular information using twenty-one Global Circulation Models (GCMs) (Taylor et al., 2012). This technique helps generate high-resolution information using global model datasets. The horizontal resolution of NEX-GDDP dataset is around 25km × 25km (0.25° longitude × 0.25° latitude) to such granular future climate estimates are helpful to assess the impacts of climate change at sub-national scales. The details of the models used have been provided in Appendix 1. The projected changes in Uttarakhand were analysed using the RCPs adopted by the IPCC.

Rainfall projections

To minimise the uncertainty in the projections using many models, the global climate community usually applies averaging of the results from different regional models which is called as multimodal ensemble techniques. The multimodal ensemble mean of NEX-GDDP models have been used to analyse changes in annual and seasonal rainfall for the near-future, mid-future, and far-future periods from 2021–2050, 2051–2080, and 2081–2099, respectively, compared to the baseline period of 1971–2005[23]. Figure 20A and Figure 20B show the percentage change in annual rainfall for Uttarakhand and its districts for the RCP4.5 and RCP8.5 scenarios. The district-wise variations in the projected change in annual rainfall for both the scenarios are shown in Figure 21. The spatial representation of projected changes in seasonal and annual rainfall estimated for different future time periods are shown in Figures 22, 23, and 24. Projected changes in annual rainfall for the RCP4.5 and RCP8.5 scenarios are given in Appendix 2.

Average annual rainfall is projected to increase under RCP4.5 by about 6%, 10%, and 16% for the near-future, mid-future, and far-future periods, respectively; while RCP8.5 projects increase by 8%, 20%, and 32% (see Figure 20). Thus, there is a notable increase in projected average annual rainfall under both the scenarios. The highest increase is projected for the monsoon season from June to July, which shows a projected change of 8%, 14%, and 21%, respectively, in near-future, mid-future, and far-future periods compared to the baseline. The post-monsoon season (October and November) also shows an increase in projected rainfall for all the periods under the both scenarios. During the winter season (December–January–February), the models project a decrease in rainfall for all the future time periods under both scenarios. Average annual rainfall for RCP4.5 shows a projected decrease during the pre-monsoon season (March–April–May) during the near-future and mid-future periods, and an increase in the far-future period; while it is projected to decrease for RCP8.5 during all three periods.

[23] The reference period is chosen to be in line with IPCC AR5 and to include the latest climate cycle which have been used as a reference period to assess future changes.

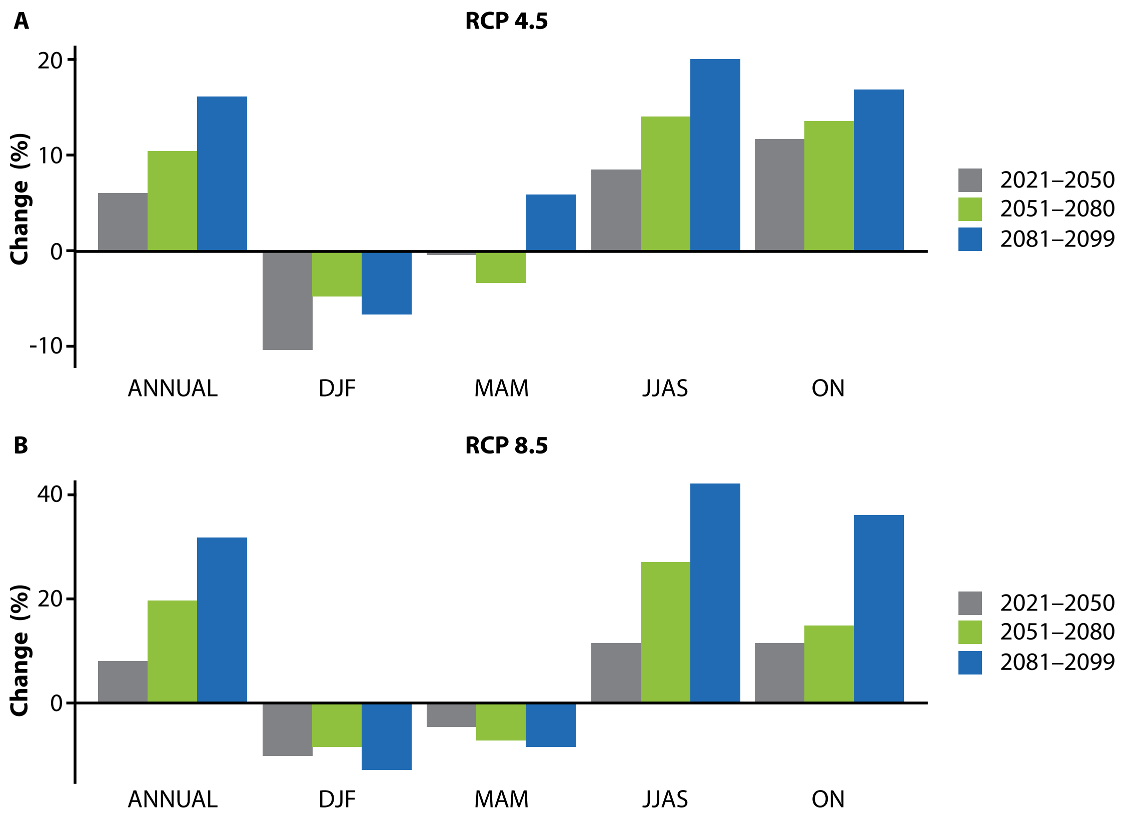


Figure 20: Projected change in annual and seasonal rainfall over the state of Uttarakhand with respect to baseline (1971–2005)

As seen in Figure 21, all the districts show a projected increase in annual average rainfall for both the scenarios. Southern districts such as Udham Singh Nagar, Nainital, and Champawat show the highest projected increase in annual average rainfall (7.5%–8%) as compared to other districts under the near-future scenario for RCP4.5. In contrast, the districts of Chamoli, Pauri Garhwal, Haridwar, and Pithoragarh show the highest projected increase (11%–12%) for the RCP8.5 near-future scenario. Towards the mid-future, Champawat and Udham Singh Nagar show the highest projected increase for both scenarios as compared to other districts. Udham Singh Nagar, Champawat, and Rudraprayag show the highest projected increase in annual average rainfall in the far-future period for both the scenarios.

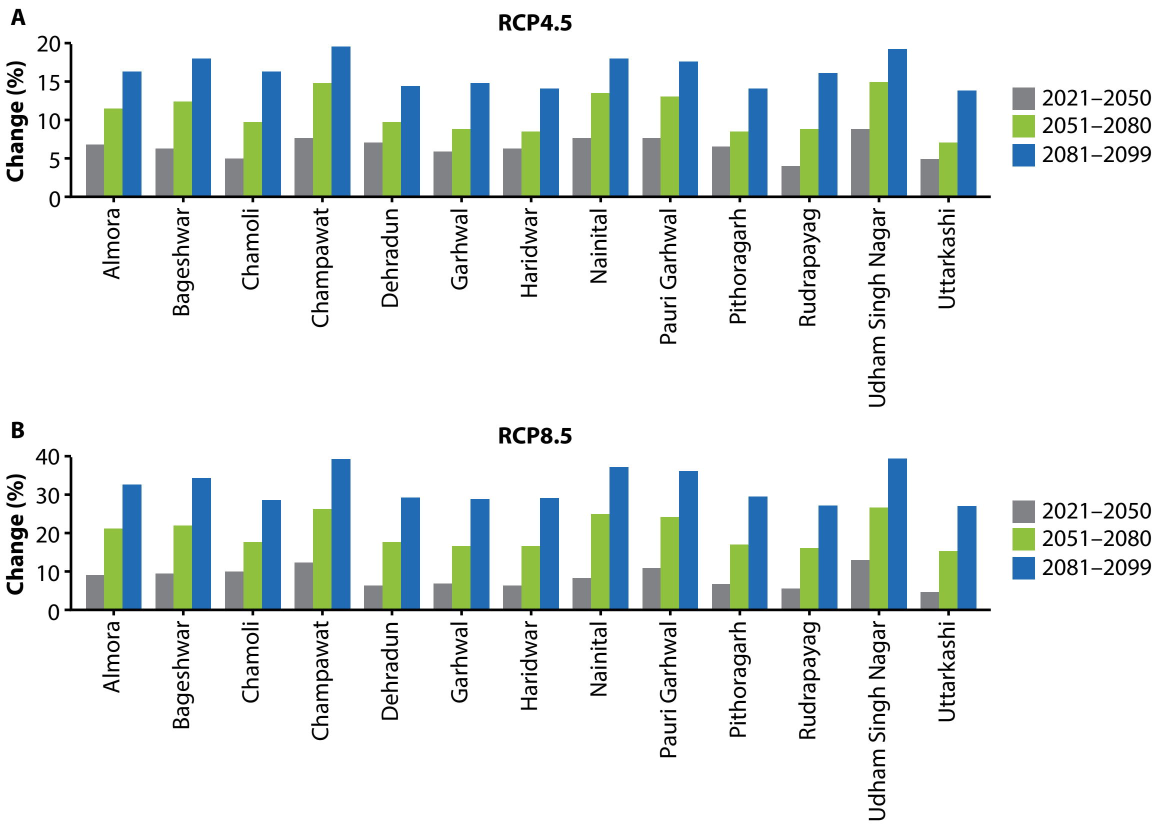


Figure 21: Projected change in annual rainfall over the districts of Uttarakhand with respect to baseline (1971–2005)

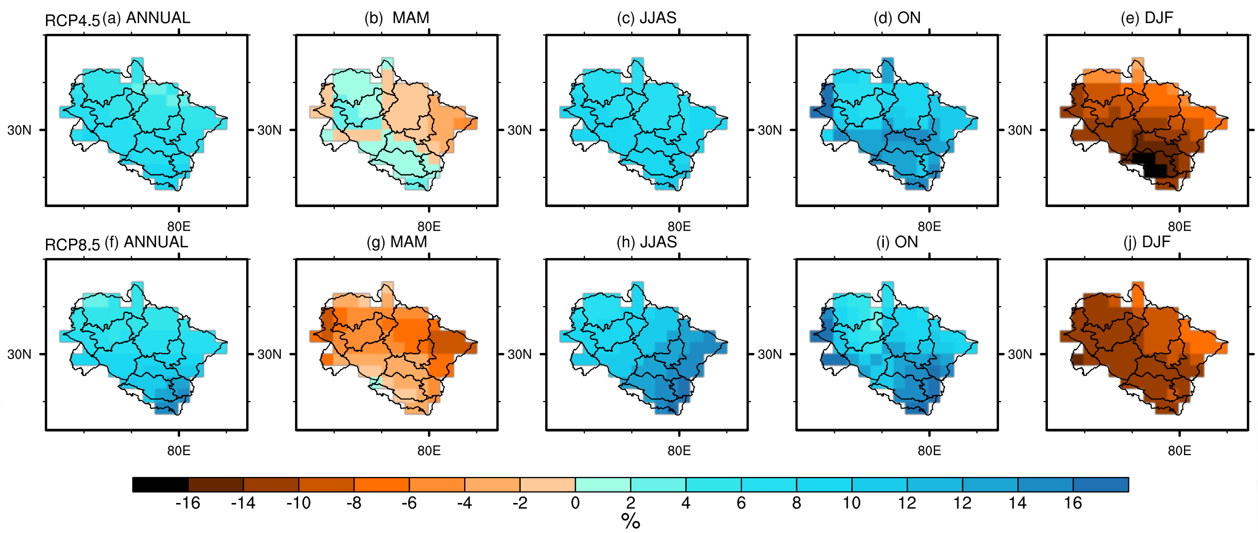


Figure 22: Projected change in annual rainfall over the districts of Uttarakhand with respect to baseline (1971–2005)

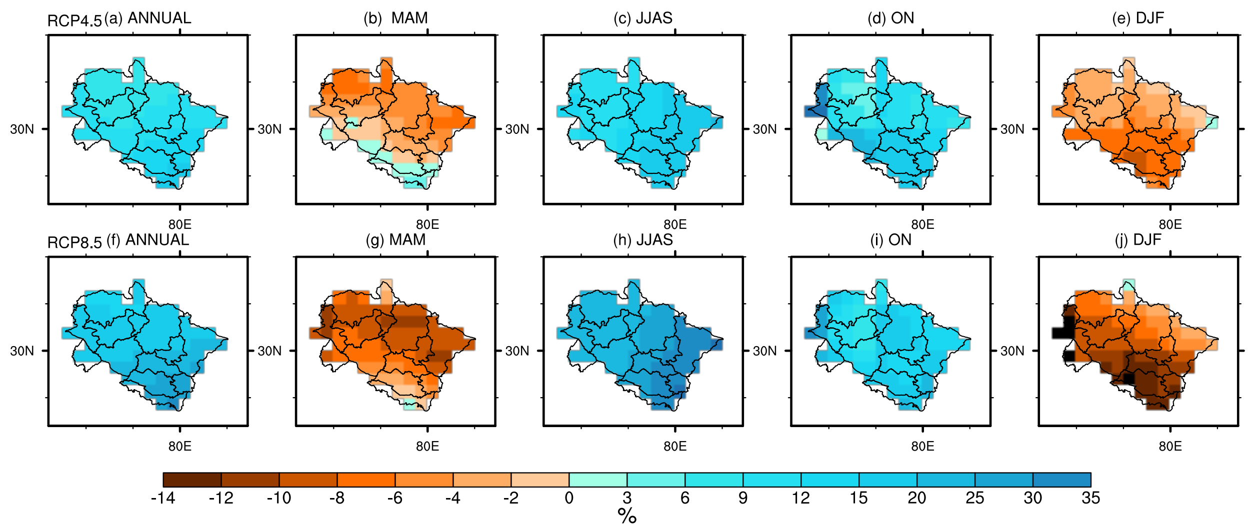


Figure 23: Projected future change in rainfall during 2051–2080 with respect to baseline (1971–2005)

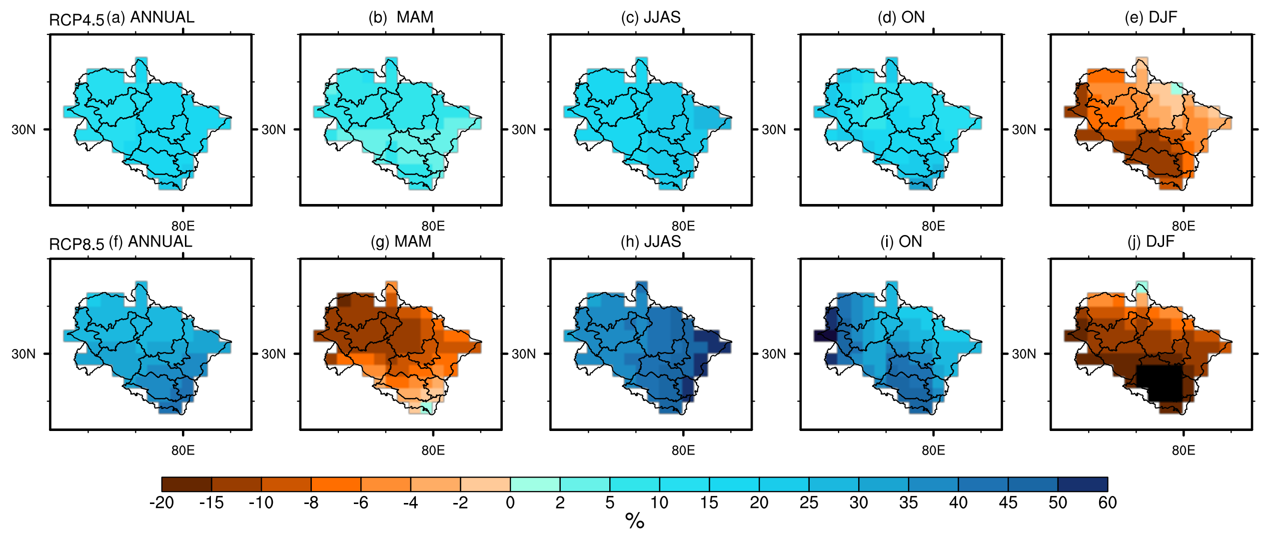


Figure 24: Projected future change in rainfall during 2081–2099 with respect to baseline (1971–2005)

Temperature projections

The Multimodal Ensemble mean of 21 NEX-GDDP models were used to analyse the future changes in annual and seasonal maximum temperatures during the near-future, mid-future, and far-future periods from 2021–2050, 2051–2080, and 2081–2099, respectively, compared to the baseline period of 1971–2005. The analysis is done for two IPCC scenarios: RCP4.5 and RCP8.5. Figures 25A and 25B show the change in annual and seasonal maximum temperatures in Uttarakhand. Figure 26 shows the average annual change in maximum temperature for the state, broken out for its districts. The spatial representations of projected changes in seasonal and annual maximum

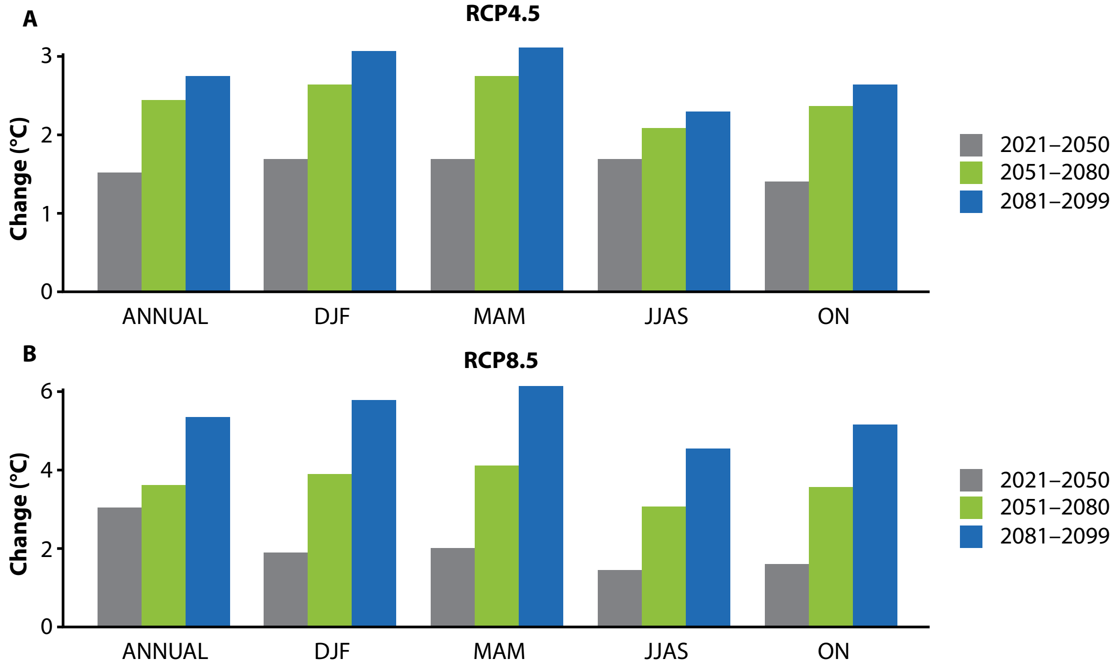


Figure 25: Projected near-future (2021–2050), mid-future (2051–2080), and far-future (2081–2099). Change in annual and seasonal maximum temperature in Uttarakhand with respect to the baseline period (1971–2005)

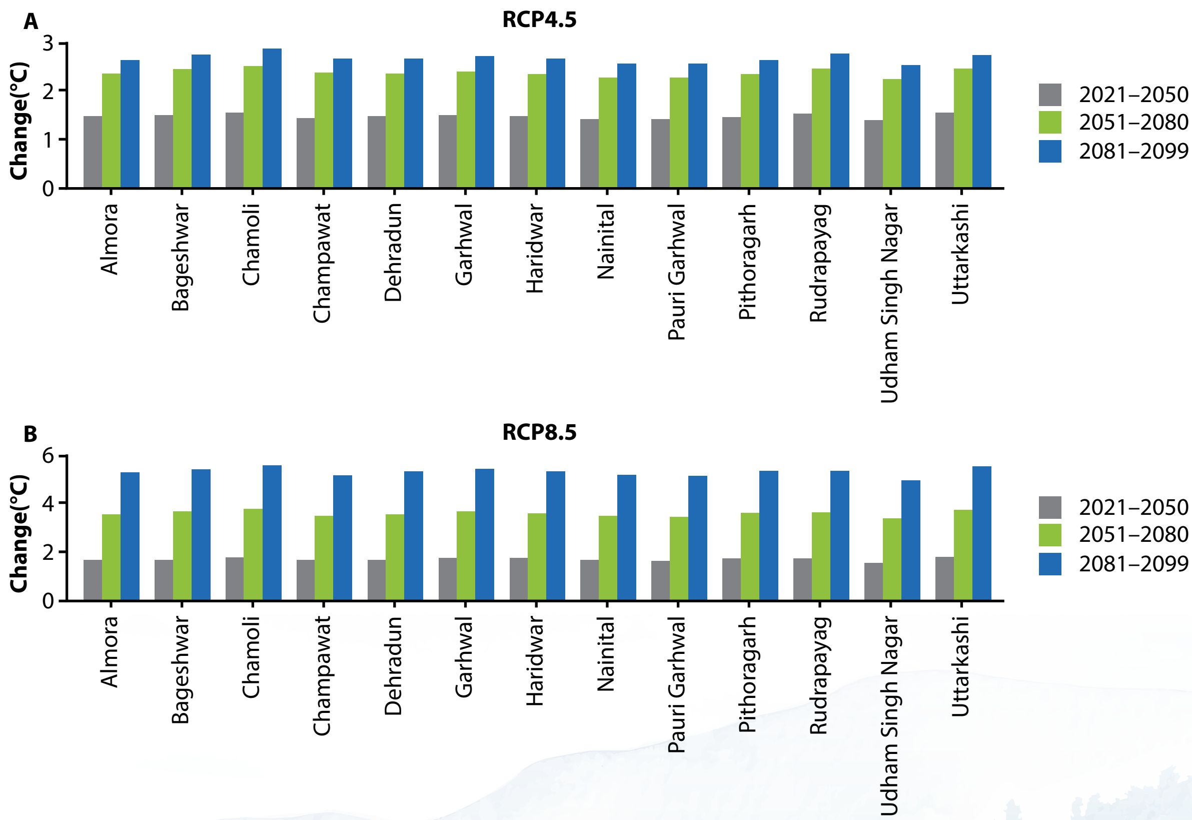


Figure 26: Projected change in annual maximum temperature with respect to baseline for the districts of Uttarakhand

temperatures are shown in Figures 27, 28 and 29. The projected change in annual maximum temperature is given in Appendix 3.

Under either RCP4.5 or RCP8.5 the annual maximum temperature is projected to increase during all seasons, in all of Uttarakhand's districts (see Figure 25). The average annual maximum temperature is projected to increase by 1.6 °C in the near-future, 2.4 °C by the mid-future, and 2.7 °C in the far-future in RCP4.5; while the temperatures are 1.9 °C, 3.8 °C and 5.3 °C, respectively, for RCP8.5. The projected change is greatest during the pre-monsoon season (March–April–May) and winter season (December–January–February) for RCP4.5 while for RCP8.5, it is projected during pre-monsoon (March–April–May) season as compared to other seasons.

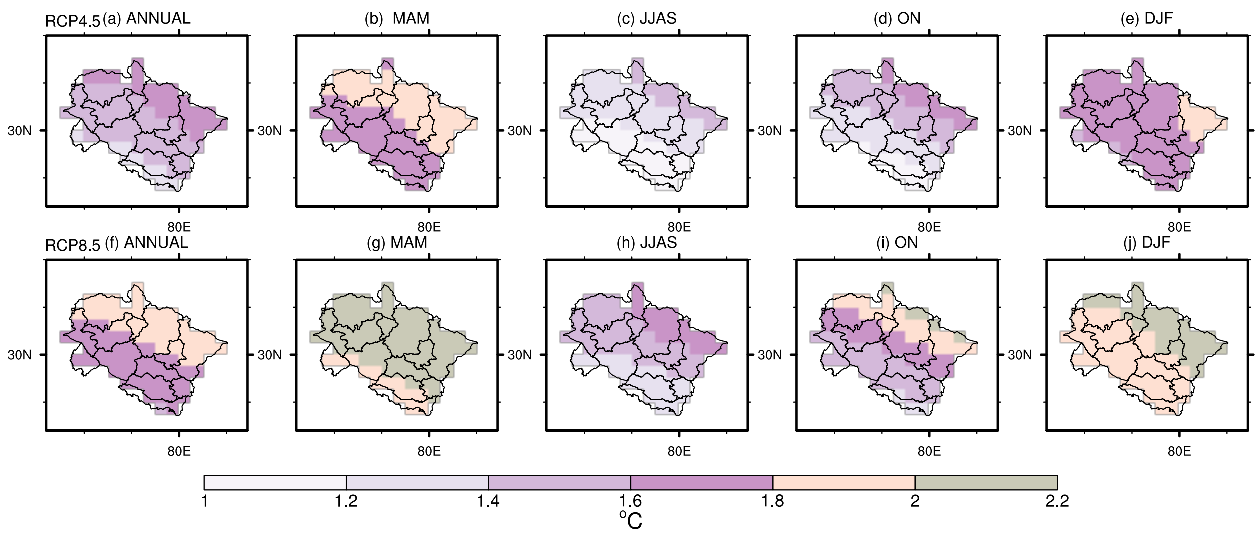


Figure 27: Projected change in maximum temperature towards 2021–2050 with respect to baseline 1971–2005 in Uttarakhand

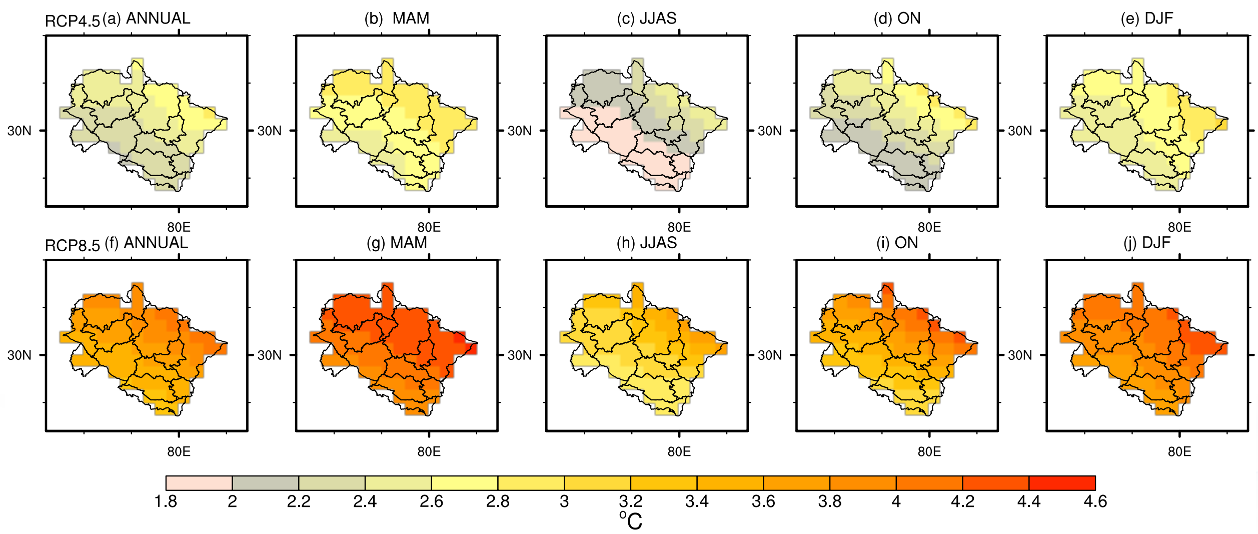


Figure 28: Projected change in maximum temperature towards 2051–2080 with respect to baseline 1971–2005 in Uttarakhand

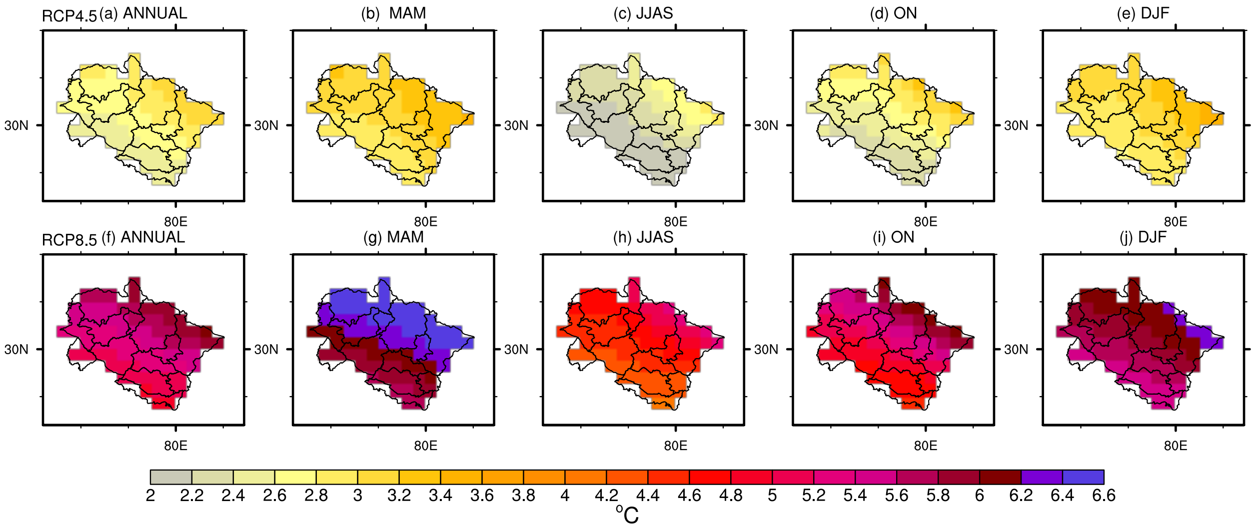


Figure 29: Projected change in maximum temperature towards 2081–2099 with respect to baseline 1971–2005 in Uttarakhand

Under both scenarios, the annual minimum temperature is projected to increase for all seasons in all of Uttarakhand, as shown in Figure 30. The district-wise projected change in annual minimum temperature is presented in Figure 31. The spatial representation of projected changes in seasonal and annual maximum temperatures

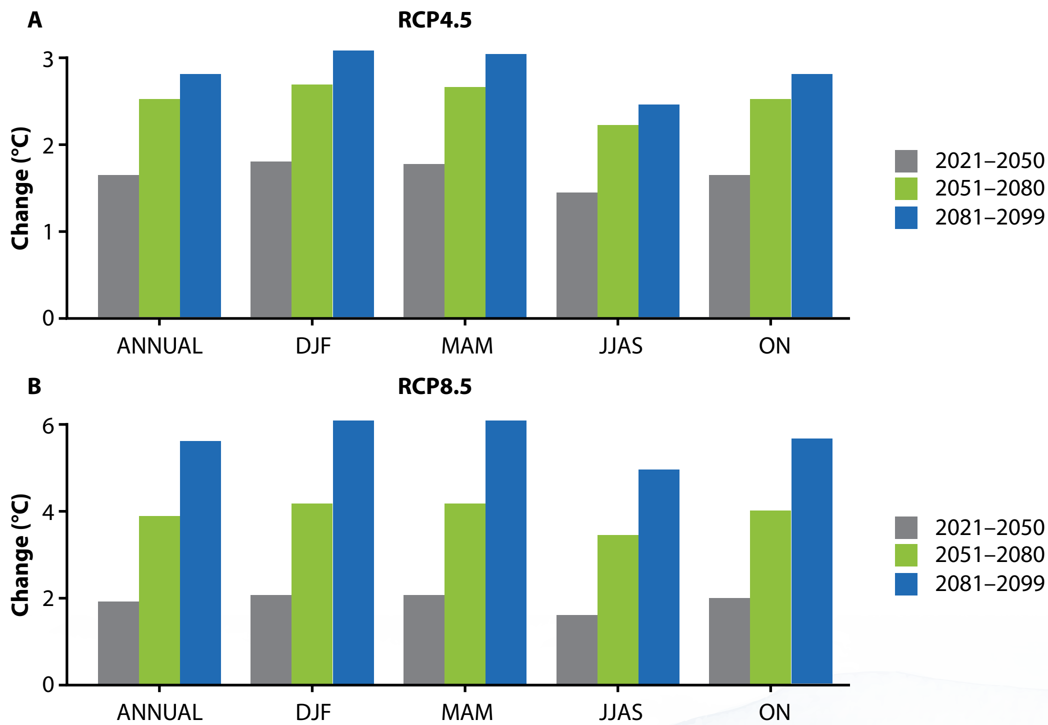


Figure 30: Projected near-future (2021–2050), mid-future (2051–2080), and far-future (2081–2099) change in annual and seasonal minimum temperature over the state of Uttarakhand with respect to baseline period (1971–2005)

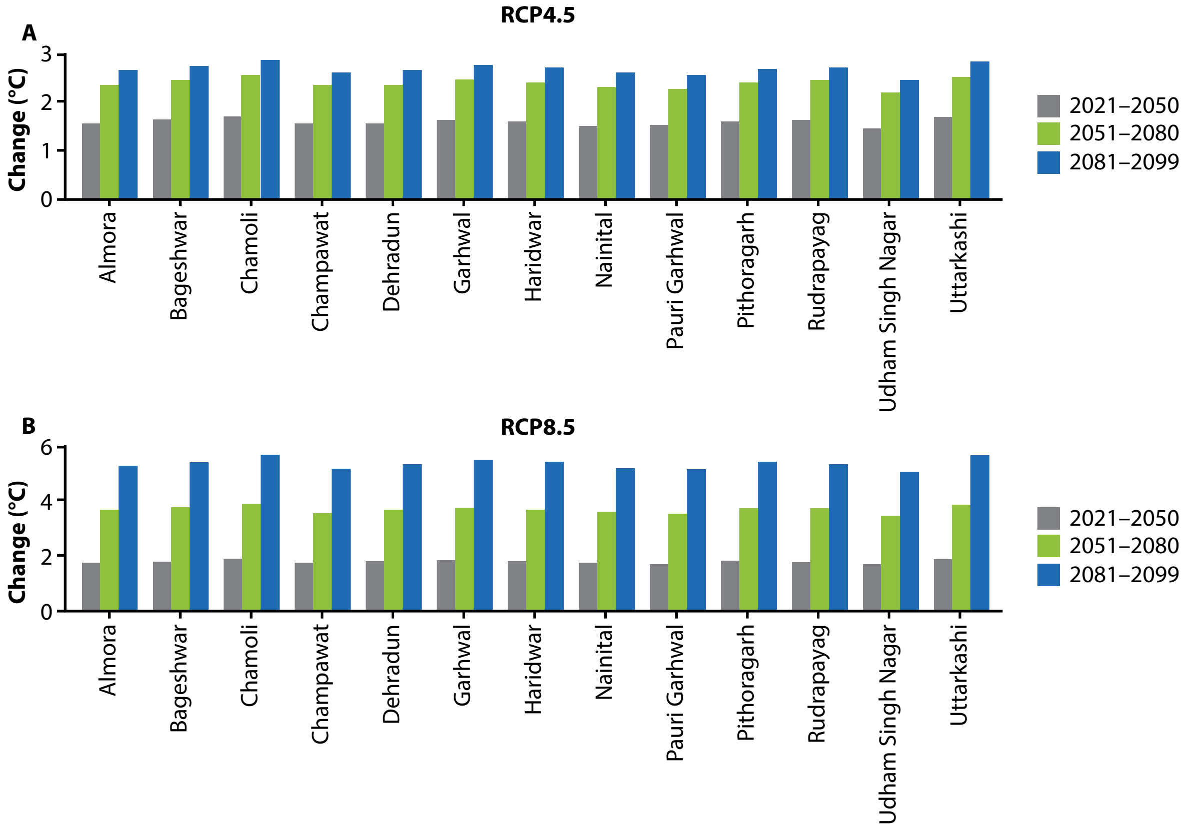


Figure 31: Projected change in annual minimum temperature with respect to baseline (1971–2005) over the districts of Uttarakhand

estimated for the state of Uttarakhand for the near-future, mid-future, and far-future are shown in Figures 32, 33, and 34, respectively. The projected change in minimum temperature is given in Appendix 4.

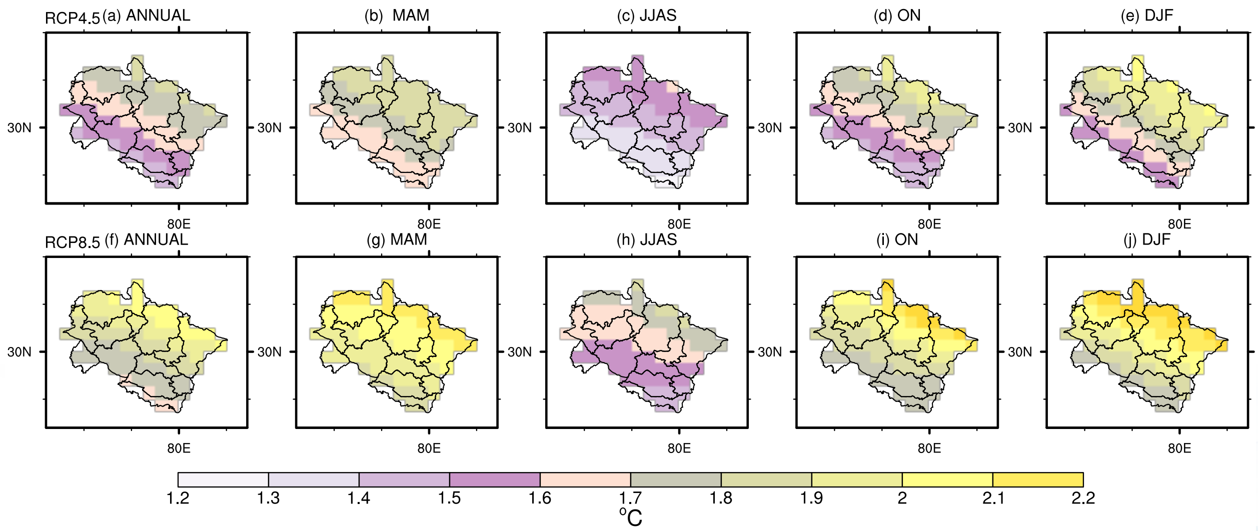


Figure 32: Projected change in minimum temperature towards 2021–2050 with respect to baseline 1971–2005 over Uttarakhand

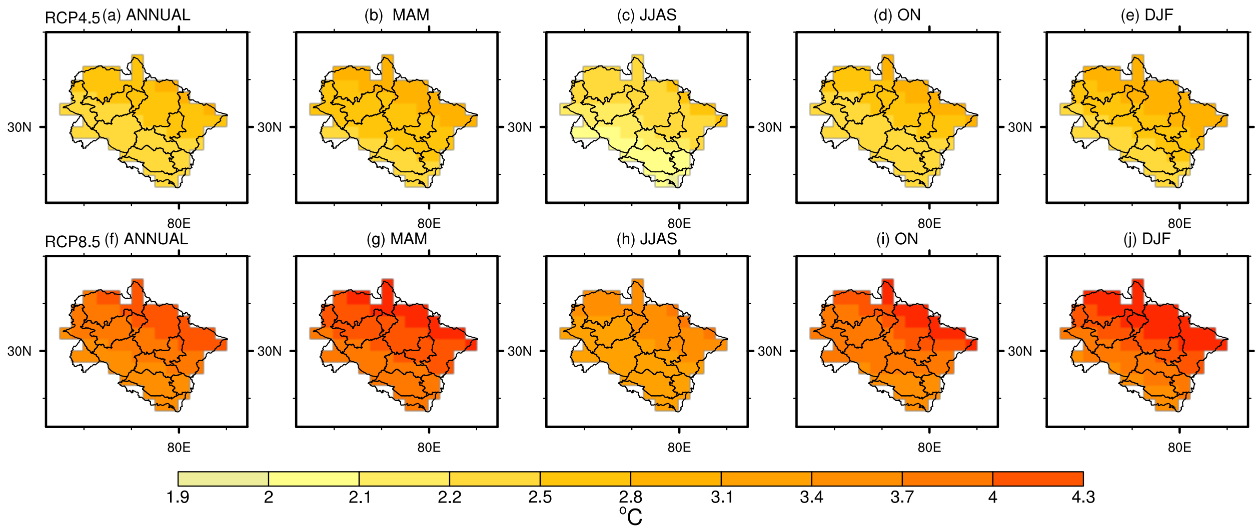


Figure 33: Projected change in minimum temperature towards 2051–2080 with respect to baseline 1971–2005 over Uttarakhand

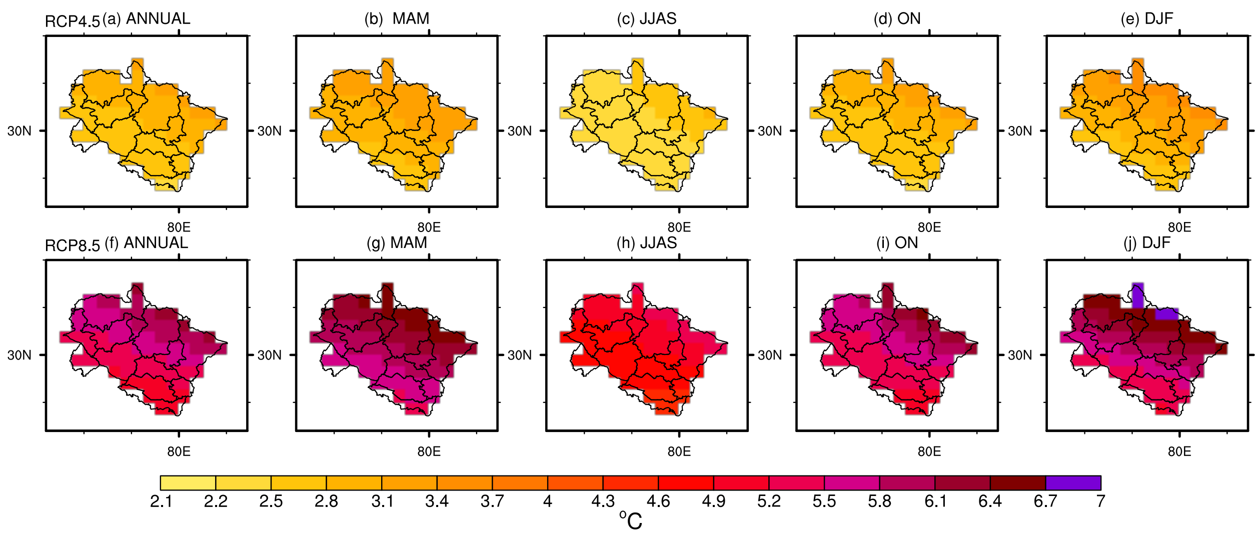


Figure 34: Projected change in minimum temperature towards 2081–2099 with respect to baseline 1971–2005 over Uttarakhand

Under RCP4.5, the average annual minimum temperature in Uttarakhand is projected to increase by about 1.5 °C in the near-future, 2.4 °C for the mid-future, and 2.7 °C in the far-future. By comparison, RCP8.5 projects an increase by about 1.8 °C in the near-future, 3.7 °C in the mid-future, and 5.2 °C in the far-future (see Figure 30). The projected change in minimum temperature shows relatively little variation across all districts for both the scenarios (see Figure 31). However, the northern districts show a higher projected change in minimum temperature than the other districts. The highest minimum temperature increases are projected for the winter season (December to February) and the monsoon season (June to September), compared to spring and autumn.

3.3 Monsoon

The most important features of the Indian climate are its two monsoon seasons. The intense heat during the summer in the month of May heats the landmass. Rising hot air from the heated landmass creates a low-pressure region over India, which attracts moist winds from the surrounding ocean. These winds blow in a south-westerly direction, establishing the southwest or Indian Summer Monsoon (ISM). Most of the subcontinent gets its rain during the summer monsoon (June to September), while the south-eastern part of country receives rainfall during the winter monsoon (November and December). The temperature difference required for this south-westerly flow exists not just at the surface, but also to a significant height in the troposphere due to surface heating at higher elevations in the Himalayas and Tibetan Plateau. These elevated regions also act as a barrier blocking the moist winds from moving further north, thus sustaining the monsoon precipitation over India. Most agricultural activities in India depend on these monsoon rains. For instance, the arrival and retreat of the two monsoons determine the cropping season. India is still primarily an agricultural economy, and as its agriculture is rain-fed in most areas, the country's gross domestic product (GDP) is heavily dependent on the monsoon rains. In Uttarakhand, hill agriculture is 'mostly of the subsistence type, rain-fed and depends on suitable weather for good yields' (Planning Commission, GU, 2017, p. 51). As mentioned earlier, 70% of state's population depends on agriculture and related activities (Planning Commission, GU, 2017, p. 51), so reliable monsoon rains are critical to the entire farm-driven economy.

Onset and withdrawal of the summer monsoon

Late or early onset and withdrawal of the monsoon may have devastating effects on agriculture even during years with normal mean annual rainfall during the monsoon season. For instance, an early monsoon arrival can lead to crops flooding (Goswami et al., 2010; Wang et al., 2009). Recent trends in the withdrawal dates of monsoons from India show a delay compared to the long-term average. This could postpone the harvest time of the kharif crops. Climate change increases the likelihood of extreme rainfall events. If these occur near the withdrawal, there is a significant chance of damage to crops ready for harvest or in the post-harvest process. Rapid pre-monsoon heating of the Himalayas–Tibetan Plateau occurs while the Indian Ocean remains relatively cool. Analysis of tropospheric temperatures reveals warming in the Himalayan–Gangetic region that could result in a stronger land–ocean temperature difference. Aerosols over the foothills of the Himalayas could cause a more substantial difference in the temperature between land and ocean, which could lead to earlier monsoon onset (Turner and Annamalai, 2012).

Monsoon rainfall over Uttarakhand and influencing factors

The considerable elevation range in Uttarakhand, from 175 m to 7000 m above sea level (Banerjee et al., 2019), results in complex rainfall patterns that add to the difficulty of projecting rainfall trends and variability (Palazzi et al., 2013) **in the future**. Various studies report that there are insufficient meteorological stations in the western Himalayan region, compounding the problem of low-quality data and missing values (Palazzi et al., 2013; Singh et al. 2014, Das and Meher, 2019). Accounting for observed trends and projections of future climate scenarios should, thus, be carefully investigated by comparing results at the stations with those from global scale simulations. In general, the south-west monsoon or ISM contributes the most to annual rainfall, providing approximately 80% of the rain for Uttarakhand (Banerjee et al., 2019). The state also receives rainfall from western disturbances originating in the Mediterranean Sea during winter. The amount of monsoon rainfall in the Western Himalayas is low compared to the western coast, central, and north-eastern regions. In the state of Uttarakhand, Banerjee et al. (2019) showed that the eastern regions receive the most monsoon rainfall, followed by the city of Dehradun, and other neighbouring areas. They also documented that the eastern part of the state has higher rainfall variability than its western and central regions. However, Dehradun, which is on the western side, also shows high variability of rainfall during the monsoon. Thunderstorms and cloudbursts occur regularly during the monsoon season (Das and Meher, 2019). These events are closely connected with heavy rainfall and floods.

Various factors influence the rainfall in the Western Himalayan region. Singh et al. (2014) suggested that both rainfall variability and the amount of precipitation decreases with increasing altitude. However, Banerjee et al. (2019) observed that rainfall decreases only up to a specific elevation (3100 m), beyond which altitude rainfall increases again. Uttarakhand is also often subject to extreme rainfall events (Das and Meher, 2019; Das et al., 2006). Aerosols[24] created by rapid urbanisation and industrialisation in recent decades also affect the monsoon rainfall in this region (Das and Meher, 2019; Turner and Anna malai, 2012) by altering the radiation reaching the surface and the air temperature. Aerosols influence cloud genesis in the monsoon's initial phase, resulting in early monsoon rainfall, but also reduced rainfall during the end of the monsoon season (Das and Meher, 2019). However, the precise impact of aerosols on current trends and future developments is still uncertain (Turner and Annamalai, 2012). Kumar and Jaswal (2016) showed the influence of North Atlantic Oscillation (NAO) and El Niño-Southern Oscillation (ENSO) on monsoonal rainfall in the Western Himalayan region. For instance, the positive phase of ENSO and negative phase of NAO both favour monsoon rainfall while their inverse phases are unfavourable (Dugam, 2008).

Current trends from station data

In general, there is a decreasing trend in monsoon precipitation over the Western Himalayan region. Meher et al. (2018) reported a negative trend in monsoon precipitation in the Western Himalayan region over the period 1901–2005. Kumar and Jaswal (2016) show a decrease in the monthly precipitation for the period 1857–2006 for the western Himalayan region with the most substantial decrease for the period of 1957–2006. Various authors have attributed this decreasing trend of monsoon precipitation to reduced thermal contrast between the Indian Ocean and the Tibetan Plateau (Duan et al., 2006), reduced regional monsoon circulation due to aerosols (Ramanathan et al., 2005), and weakening influence of the North Atlantic Oscillation and Southern Oscillation (Kumar and Jaswal, 2016). Singh et al. (2014), using monthly rainfall readings from thirteen surface observation stations in Uttarakhand, shows that there is no consistent spatial pattern of monsoon rainfall. The lower-elevation station of Dehradun showed a positive trend from 1978 to 2007, while the low-elevation station at Roorkee registered no particular trend. Higher-elevations stations also showed no significant trend except for Joshimath, which recorded a significant negative trend of monsoon rainfall. Additionally, the study demonstrates that rainfall variability is low during the monsoon season at all stations compared to other seasons. Banerjee et al. (2019) investigated current trends of monsoon rainfall in Uttarakhand and described the region of Munsiyari as highly prone to increased rainfall. They also demonstrated an increasing trend of rainfall in the east, some regions in the west, and central Uttarakhand. However, the authors observed decreasing trends of rainfall in the north-central and south-central regions.

[24] Scattering aerosols reflect radiation from the sun thereby reducing surface temperature. Absorbing aerosols absorb radiation and warms the atmosphere.

Contrast between expected trends and observations

Although monsoon rain was expected to increase in the past few decades, rainfall observations in many regions of India do not show an increase in rainfall. Under global warming, the land–sea temperature contrast, which determines monsoon strength, is expected to increase and lead to higher precipitation (Chou, 2003; Sutton et al., 2007). Furthermore, the Indo-Pacific oceans have already warmed over the past fifty years (Knutson et al., 2006), which might be expected to increase the supply of moisture to the subcontinent. However, despite this potential for increased monsoon rains, observations show that only the month of June is receiving more rain than before during the entire monsoon season. The trends for July, August, and September actually show declining rainfall. This decline is also evident in the larger north-western region of India (Pattanaik, 2007). Significant decreasing trend of monsoon rainfall occurred over 1901–2012 in many regions of India. A study using multiple observed datasets shows a notable weakening trend in summer monsoon precipitation during this period, south of the Western Ghats, and in the central-east and northern regions of India (Roxy et al., 2015). The authors associated the weaker monsoon with the decreasing land–sea thermal gradient, with rapid warming in the Indian Ocean and relatively subdued warming of the subcontinent brings their temperature levels closer together. Long-term summer monsoon rainfall data from 1871 to 2005, collected at over thirty meteorological subdivisions of India, was studied for the months of June through September (Naidu et al., 2009). For the period of 1970 to 2005, they showed a negative trend for rainfall (less rainfall than before) dominant over most of the subdivisions, particularly north of 20° N, which includes the Western Himalayan region.

The higher elevation area of the Western Himalayan region has more heavy rainfall events during the monsoon, which can cause flooding in the lower levels (Sen, 2009). It has been suggested that, despite the evidence from the summer months, warming in the region could increase the amount of extreme rainfall during winter (Meher et al., 2018). Using station data from 1957–2007, Singh et al., (2014) report that monsoon rains in Uttarakhand have declined at high altitudes and increased at low altitudes. However, the trends are not uniform across all stations.

Studies using coupled general circulation models (CGCM) show higher rainfall over South Asia, but not in the Western Himalayan region (Turner and Annamalai, 2012). Strengthened monsoon rainfall results from higher atmospheric moisture content over the warmer Indian Ocean (Douville et al., 2000). Models developed by the Coupled Model Inter Comparison Project (CMIP3) show an increase in South Asian monsoon rainfall despite weakening monsoon circulation (Ueda et al., 2006). Although a multi-model mean study does project higher rainfall in the Western Himalaya region, the trend is not significant (Turner and Annamalai, 2012).

Models at the regional scale also show contrasting trends. In recent decades, South Asia has witnessed an increase in aerosol content due to rapid urbanisation and industrialisation (Bond et al., 2013; Menon et al., 2002) leading to reduced insolation at the surface. This might explain why increased seasonal mean rainfall over India has not been observed despite global warming. A review of factors affecting the Western Himalayan climate by Das and Meher (2019) shows the current debate on the impact of aerosols on the monsoon in the Western Himalayan region. Meher observes that most of the CMIP3 and CMIP5 GCM[25] failed to reproduce the short- and long-term trends of precipitation (Meher et al., 2017). The authors also reported that most GCMs failed to reproduce the long-term patterns of precipitation.

[25] In this section GCM refers to Global Climate Models.

Projections of monsoon using regional scale models

The analysis on the area average precipitation over Uttarakhand by Banerjee et al. (2019) shows increasing trends of rainfall using historical data. They show stagnated precipitation trends for RCP2.6 and RCP4.5. However, they project significant decreasing trends of rainfall for RCP8.5. According to the Government of Uttarakhand Action Plan on Climate Change (GU, 2014), based on regionally downscaled projections from CORDEX simulations, the following conclusions can be drawn for the monsoon: 1) during the monsoon season, the northern parts of Uttarakhand will receive relatively low rainfall compared to the southern parts; 2) for different RCP scenarios, some districts in the north show increased rainfall while southern districts show decreased annual rainfall in the mid-century compared to the historical baseline case; 3) the highest rainfall increase projected for the monsoon season is for the mid-century and end-century under the IPCC AR5 RCP4.5 scenario.

Gaps

The failure of many GCM models to reproduce the climatology patterns and trends of observed precipitation shows the need for regional-scale models to study the impact of climate change on monsoon trends in Uttarakhand. Palazzi et al. (2015) reported the inability of GCMs to represent the regional conditions such as the elevation patterns, orographic lifting, (Palazzi et al., 2015). However, certain GCMs on low-resolution were able to perform better than high-resolution models (Meher et al., 2017). Sperber et al. (2013) reported that CMIP5 models show better performance simulating the rainfall patterns at the foothills of Himalayas than do CMIP3 models. Such models should be used to analyse the impact of large-scale forcing (ENSO, NAO, SO, etc.) on the precipitation patterns and trends in Uttarakhand, and for use in downscaling models. It is also vital to understand how different type of aerosols affect the precipitation patterns of Uttarakhand. As the station data shows no consistent pattern for historical trends, the state needs to improve the density and reliability of its meteorological stations. Banerjee et al. (2019) suggested that the IMD dataset is not reliable since it is station interpolated. More observations are essential to validate results from regional scale models. Further, as the number of extreme rainfall events have increased during the monsoon, their effects on Uttarakhand's complex topography should be investigated. Meteorological conditions, particularly in the Western Himalayan region, have not been studied comprehensively at the micro-scale, so trends of monsoon precipitation in this region are yet to be adequately understood (Fowler and Archer, 2006).

3.4 Extreme Weather Events

Uttarakhand's socio-economic reliance on climate-sensitive sectors such as agriculture, forestry, and tourism render it highly vulnerable to climatic shocks (GU, 2014; INRM, 2016a). An increasing number of extreme weather events in the Himalayas – heavy precipitation-induced cloudbursts, flash floods, and avalanches – are adversely impacting the human lives and the state's economy (Kumar et al., 2018). Uttarakhand has experienced many extreme weather events since 1816, but the intensity and frequency of such events have notably increased since 1970 (Pandey and Mishra, 2015). These events have not only caused serious economic damage but led to the loss of thousands of lives.

Historical Climate Extreme Indices[26]

Various climate extreme indices have been analysed for the state of Uttarakhand in recent decades (INRM, 2016b; Ca et al., 2018). The indices are based on daily precipitation totals as well as daily maximum and minimum temperatures. They help monitor the risks and quantify the shifting occurrence of climatic extremes over time, such as changes to the heaviest daily and monthly rainfall totals, or the intensity and duration of heatwaves. Table 6 details the climate extreme indices reviewed in this report.

Table 6: Details of climate extreme indices reviewed

Descriptive Name	Definition	Unit
One-day maximum precipitation	Highest precipitation amount in a one-day period	mm
Five-day maximum precipitation	Highest precipitation amount in a five-day period	mm
Consecutive dry days	Maximum length of a dry spell (consecutive days with precipitation less than 1 mm)	Days
Consecutive wet days	Maximum number of consecutive wet days	Days
Heavy precipitation days	Count of days when precipitation >90th percentile of the baseline[27]	Days
Very heavy precipitation days	Count of days when precipitation >99th percentile of the baseline[28]	Days
Warm spell duration indicator	Annual count of days with at least six consecutive days, when the maximum temperature > 90th percentile of base period maximum temperature	Days
Warm days	Percentage of days when maximum temperature > 90th percentile of the baseline[29]	Days
Very warm days	Percentage of days when maximum temperature > 95th percentile of the baseline[30]	Days
Cold spell duration indicator	Annual count of days with at least six consecutive days, when minimum temperature is <10th percentile of base period minimum temperature	Days
Maximum of day time temperature	Monthly maximum value of daily maximum temperature	°C
Maximum of night time temperature	Monthly maximum value of daily minimum temperature	°C
Minimum of day time temperature	Monthly minimum value of daily maximum temperature	°C
Minimum of night time temperature	Monthly minimum value of daily minimum temperature	°C

[26] The IPCC defines an 'extreme climate or weather event' or 'climate extreme' as 'the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable'(Field et al., 2012, p. 116) . The IPCC further adds that 'the distinction between extreme weather events and extreme climate events is not precise, but is related to their specific time scales: –An extreme weather event is typically associated with changing weather patterns, that is, within time frames of less than a day to a few weeks. An extreme climate event happens on longer time scales. It can be the accumulation of several (extreme or non-extreme) weather events (e.g., the accumulation of moderately below-average rainy days over a season leading to substantially below-average cumulated rainfall and drought conditions)(Field et al., 2012, p. 117).

[27] The 90th percentile rainfall event represents an event in which the precipitation amount never exceeds 90% of all rainfall event amount for the analysed period.

[28] The 99th percentile rainfall event represents an event in which the precipitation amount never exceeds 99% of all rainfall event amount for the analysed period.

[29] The 90th percentile temperature event represents an event in which the daily temperature never exceeds 90th percentiles for the period of record.

[30] The 95th percentile temperature event represents an event in which the daily temperature never exceeds 95th percentiles for the period of record.

Descriptive Name	Definition	Unit
Cool nights	Annual Percentage of days where minimum temperature <10thpercentile of the base period	%
Cool days	Annual Percentage of days where maximum temperature <10thpercentile of the base period	%

From 1951 to 2013, maximum one-day and five-day precipitation in the Uttarkashi district shows a significant positive trend, whereas the five-day maximum precipitation has decreased significantly in the district of Dehradun. The number of consecutive dry days is rising non-significantly for most of the districts, and wet days are decreasing significantly for all districts (INRM, 2016a). The number of days with precipitation greater than 10 mm or 20 mm also shows a declining trend for all districts of Uttarakhand. The significant increasing trend of average precipitation on wet days for districts such as Chamoli and Rudraprayag imply that rainfall intensity has increased during the study time period, and a significant decreasing trend has been observed in districts such as Pauri Garhwal and Dehradun for the same time period. In addition, the districts of Pauri Garhwal and Nainital are most prone to moderate droughts, whereas Udham Singh Nagar and Bageshwar are most prone to severe droughts. Udham Sing Nagar and Champawat are most prone to moderate floods (INRM, 2016b).

The hill regions of Uttarakhand recorded extreme rainfall during October and January, while plains areas recorded extreme rainfall during the monsoon months of June to September. The major flood event of 14–18 June 2013, during which about 6000 people were killed, found missing or presumed dead, was mainly attributed to a cloud burst along with the rapid melting of glaciers in Chorabari Lake. During the extreme four-day rainfall, 370 mm/day was recorded at Dehradun, which is nearly 27% of the usual annual rainfall (Nandargi et al., 2016). This was the first time such a heavy rainfall event occurred in June.

Projecting future extreme events

Rainfall

Since the global climate changes can have a severe impact at the regional and local levels, future climate extremes must be assessed at a granular scale in order to develop a robust adaptation strategy. **Heavy rainfall events are projected to increase across all the districts of Uttarakhand** as shown in Figure 35. Although the greatest projected change is seen in the far-future period, the number of heavy rainfall days is expected to be higher in RCP8.5 than in RCP4.5. The district of Rudraprayag shows the biggest projected increase in heavy rainfall days, with an increase of 13%, 16%, and 17% for the near-future, mid-future, and far-future scenarios, respectively. The Garhwal district shows the least projected change in the number of days with rainfall greater than the 90th percentile of the baseline. The projected increase in heavy rainfall events for Uttarakhand parallels the global projected increase in the frequency of extreme weather events. Such heavy rainfall events increase the risk of flash flooding (Trenberth, 2008), resulting in the destruction of life and property.

Consecutive wet days are also estimated for all the districts in the state of Uttarakhand and it shows mix behaviour over different districts. For some districts, it shows that it will increase in the future while some districts show a decrease, as depicted in Figure 36, which shows the change in the maximum number of consecutive wet days in the near-future, mid-future, and far-future periods with respect to the baseline period of 1971–2005. Wet days are defined as the number of days with rainfall over 1 mm. There is a variation across districts, with Almora, Champawat, Garhwal, Haridwar, Nainital, and Rudraprayag showing an increase for all the time periods under

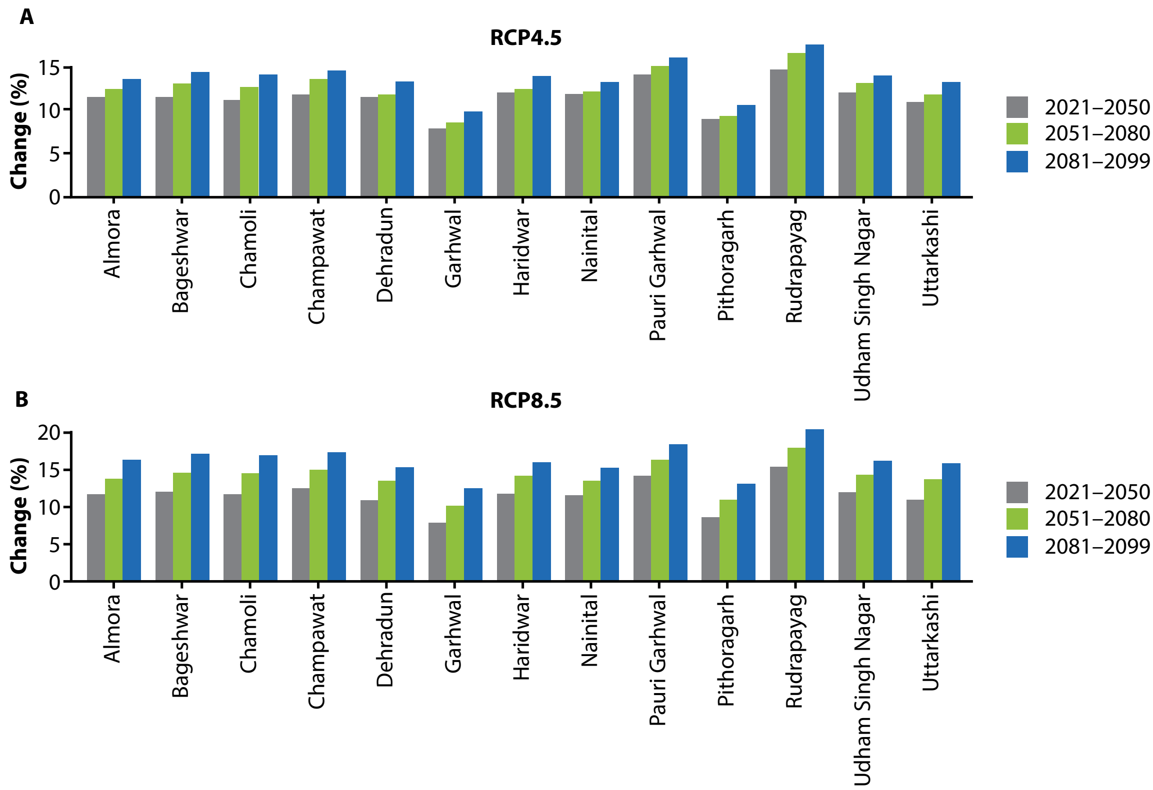


Figure 35: Projected changes in heavy precipitation days (rainfall >90th percentile) with respect to baseline (1971–2005).

RCP4.5; while Champawat, Nainital and Rudraprayag show an increase over all the time periods only for RCP8.5. An INRM assessment also shows that consecutive dry days are projected to increase during the near-future and far-future compared to the baseline (1981–2010) (INRM, 2016a).

Future projections of extreme rainfall events by Ca et al. (2018) point to a possible increase of 15% in 99th percentile rainfall in the districts of Uttarkashi, Dehradun, Tehri Garhwal, and Rudraprayag; and a slight decrease in Udham Singh Nagar, Nainital, and Champawat during 2021–2050 relative to 1961–1990. The maximum rainfall in a single event is also projected to increase marginally in the southern districts. The precipitation extreme indices as projected by INRM (2016a) show a significant increasing trend in the near-future for RCP8.5 scenario for most of the districts. Districts such as Almora, Bageshwar, Champawat, Nainital, and Udham Singh Nagar are projected to have a significant increase in annual rainfall and very heavy precipitation days during near-future. Rainfall intensity and the number of consecutive wet days are projected to increase for all the districts during the near-future for RCP8.5. The projected increase in rainfall is reflected in the decrease in the drought proneness and is expected to decrease in most of the districts except in Uttarkashi, Chamoli, Bageshwar, and Pithoragarh.

Changing climate has significant implications on facing floods and droughts over a particular area in a way that although total rainfall has remained the same, the extreme rainy days have increased, which also have resulted in increase of number of dry days. Such kind of rainfall behaviour not only results in flooding events but also

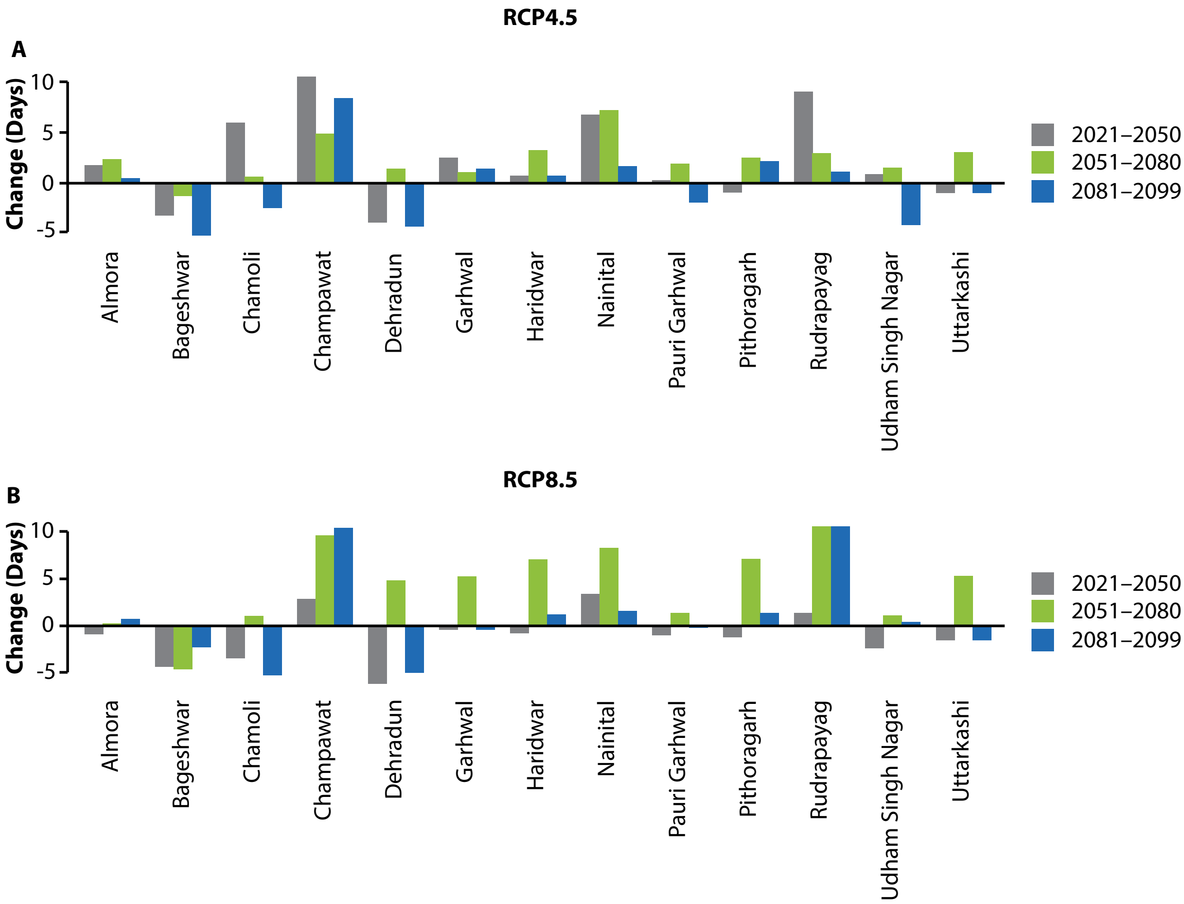


Figure 36: Projected change in consecutive wet days w.r.t the baseline (1971–2005) over the districts of Uttarakhand

simultaneous drought events. It is also seen from the studies that the incidence of dry spells of at least fourteen days is projected to decrease in all the districts of Uttarakhand except in Champawat, where it is projected to increase (Ca et al., 2018).

Temperature

In order to assess future changes in extremes of temperature, warm and very warm days have been analysed which correspond to the percentage of days where the maximum temperature is greater than 90th and 95th percentile of the baseline, respectively. The warm and very warm days are projected to increase across all districts in Uttarakhand in both RCP4.5 and RCP8.5 scenarios, as shown in Figures 37 and 38. The largest changes are observed in the far-future period (2081–2099) for both scenarios.

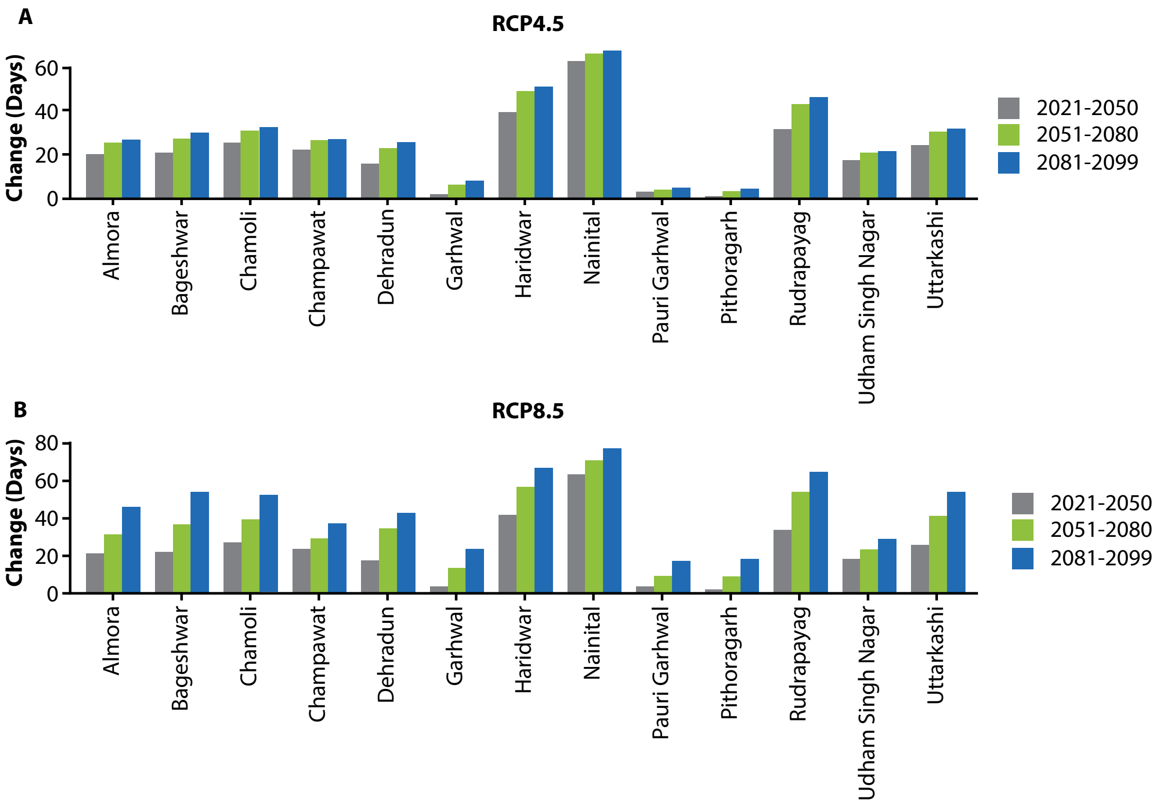


Figure 37: Projected change in the number of days with maximum temperature >90th percentile with respect to baseline (1971–2005)

The changes are projected to be strongest for the Nainital district for all time periods under both the scenarios. Projections show considerable changes in extreme temperature events for the future (Ca et al. 2018; INRM 2016a). **The frequency of warmer days is projected to increase in all the districts except Chamoli and Pithoragarh**. The number of unusually cold days is projected to decrease throughout the state except in Tehri Garhwal (Ca et al., 2018).The number of days when the temperature falls below 0 °C is projected to decrease in all districts except Chamoli and Pithoragarh (Ca et al., 2018). As defined in Table 6, the maximum of daytime/night time temperature, warm nights, warm days, and warm spell duration indicators are projected to increase significantly for the near-future and far-future for both RCP4.5 and RCP8.5 scenarios whereas, cool nights, cool days, and cold spell are expected to decline (INRM, 2016a). The indicators also show that higher warming will be observed more towards the far-future than during the mid-future, compared to the baseline (1981–2010) (INRM, 2016a).

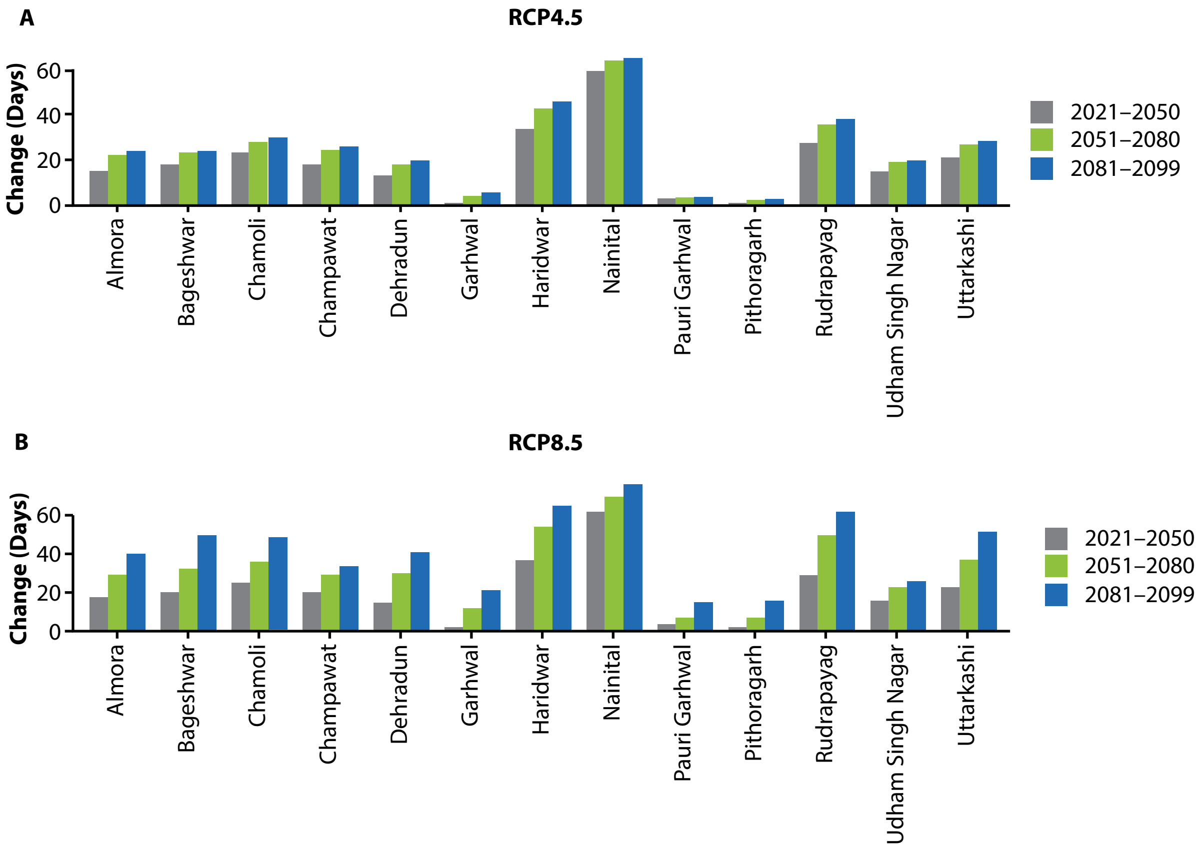


Figure 38: Projected change in the number of days with maximum temperature >95th percentile with respect to baseline (1971–2005)

3.5 Climate Change Vulnerability Profile of Uttarakhand's Districts

The beginning of this chapter discussed the challenges involved in assessing the impacts of climate change in mountain regions, including natural intra- and inter-annual variability of climatic variables or data scarcity. Considering these challenges, the scientific evidence basis for informed decision-making is often rather scarce in mountain regions, particularly at lower levels of government. In Uttarakhand, however, actors like the State Climate Change Centre (SCCC)[31] have helped to establish an evidence base to assess climate-related changes and challenges at both the district and the block levels (see the Uttarakhand State Action Plan on Climate Change (GU, 2014); and the district and block levels climate change vulnerability assessments (INRM, 2016b). This section reviews such assessments at the district level in Uttarakhand through the lens of vulnerability (for a short general introduction to 'vulnerability' in climate impact research, see Box 3). Without an understanding of the climate-related vulnerabilities of mountain ecosystems and mountain life at small scales, measures taken to respond to them may be ineffective or, worse, counterproductive. With so many depending on agriculture, mostly subsistence-based and rain-fed, for their livelihoods, vulnerability assessments for the agricultural sector are particularly relevant. A climate-induced decline in agricultural output, for instance, may result in increased vulnerability of large parts of the population.

[31] In 2016, the State Climate Change Centre (SCCC), Uttarakhand was established to strengthen and coordinate the state's climate actions, including the State Action Plan on Climate Change (SAPCC) or vulnerability and risks assessments. Along with others, the United Nations Development Programme (UNDP) helped to fund the SCCC. Source: http://sccc-uk.org/.

This section, thus, presents a district-wise climate change vulnerability profile for the state, with particular focus on climate change-related vulnerabilities in the agricultural sector. Understanding the dynamics in agriculture is necessary to understand the climate–migration nexus in Uttarakhand (discussed in detail in Section 5.2).

Box 3: Vulnerability in climate impact research

Across academic disciplines, vulnerability research aims to understand the factors that make a specific system, a unit, or an individual susceptible to harm. In climate impact research, vulnerability assessments are tools to understand the impacts which the adverse effects of climate change cause or may cause on a wide range of impacts across sectors and societies worldwide. They help to identify regions, sectors, or sections of the society which are particularly at risk by current and projected climate change and, accordingly, help to prioritise measures and funding. In the IPCC's *Fifth Assessment Report* (AR5), vulnerability is defined as the '[t]he propensity or predisposition to be adversely affected' (Mach et al., 2014). Among other factors, this includes 'lack of capacity to cope and adapt' (Mach et al., 2014). Considering different conceptualisations of vulnerability in the climate change literature and the complexity involved in analysing human-environment interactions per se, it can be a challenging task to assess the factors influencing this 'predisposition'. Physical exposure and other factors, such as socio-economic variables, interact. There is no 'one-size-fits-all' approach for choosing indicators, vulnerability assessments have to be place- and context-specific. As noted above, data scarcity may limit approaches to assess vulnerability.

The literature presented in this section often conceptualise vulnerability as the combination of exposure, sensitivity, and adaptive capacity, based on the definition of the *Fourth Assessment Report* (AR4) of the IPCC[32]. Since then the IPCC's understanding of vulnerability has changed[33] and it is furthermore acknowledge that '[v]ulnerability encompasses a variety of concepts'(Mach et al., 2014).[34] Thus, climate vulnerability assessments should discuss their underlying understanding and conceptualisation of vulnerability.

District-wise current vulnerability profile

Some of Uttarakhand's districts are already experiencing high levels of vulnerability to climate change. The hill districts of Champawat and Tehri Garhwal were found to be most vulnerable to current levels of climate change in a report prepared by Integrated Natural Resources Management Consultants (INRM Consultants), in association with the Indian Institute of Science, Bangalore (IISc Bangalore) and Geo Climate Risk Solution (INRM, 2016b). The report analysed Uttarakhand's vulnerability to current and projected climate change for specific sectors at the district and block levels (INRM, 2016b). For each district, several indicators from selected sectors are assessed (for list of indicators, see INRM, 2016b, pp. 48–52). The report provides sector-specific vulnerability rankings as well as an overall vulnerability ranking based on an aggregated composite vulnerability index[35]. Based on these rankings,

[32] In AR4, vulnerability is defined as 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity'.

[33] A good overview of the IPCC's conceptualisation of vulnerability over time can be found in a publication of the Inter-ministerial Working Group on Adaptation to Climate Change of the German Federal Government (Buth et al., 2017) or see here (GIZ and EURAC, 2017) for an overview of how to apply the concept of vulnerability according to the IPCC AR5 concept of climate risk.

[34] The full definition of vulnerability in AR5 is as follows: "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Mach et al., 2014).

[35] The report currently is one of the most comprehensive efforts to assess climate change vulnerability at district and block levels in Uttarakhand. In the case of the current vulnerability profile, the assessment is based on 28 socio-economic indicators – including sex ratio, statistics on household welfare or the healthcare infrastructure in that region – and 50 environmental indicators from selected sectors [water, forestry, agriculture and livestock, health as well as the flood and landslide risk of infrastructure; Table A-1 in the Appendix of the INRM report lists all indicators, See (INRM, 2016b, pp. 48–52)]. A composite socio-economic vulnerability index and a composite environmental index are created, contributing to an aggregated composite vulnerability index for each district. The process is described in detail in the report. It includes, inter alia, the normalisation of indicator values in order to be able to compare them as the wide range of indicators are available and/or collected in a variety of statistical units. Their weights are determined and then aggregated.

districts are grouped in one of six different vulnerability categories (very low, low, moderate, high, very high, and extremely high). While no district of Uttarakhand is categorised as having an 'extremely high' degree of overall vulnerability to current climate change, the hill districts of Champawat and Tehri Garhwal have a 'very high' degree of overall vulnerability. The authors attribute the vulnerability of these two hill districts to 'their relatively low adaptive capacity, higher sensitivity, and exposure with respect to the other districts' (INRM, 2016b).[36]

Climate change-related vulnerability is likely to increase in the agricultural sector of hill districts. When just looking at the agricultural sector, four hill districts – Tehri Garhwal, Almora, Champawat, and Pauri Garhwal – are categorised with a 'very high' vulnerability to current climate change (INRM, 2016b). The vulnerability assessment of the agricultural sector is based on thirteen indicators, which take into account things such as crop yield, water supply systems, or the percentage of small landholdings (below one hectare). Of the sixteen blocks in Uttarakhand classified as having a 'very high' degree of vulnerability to current climate change, thirteen are located in one of these four hill districts. Another vulnerability assessment, carried out by the International Centre for Integrated Mountain Development (ICIMOD) in the hill districts of Almora, Bageshwar and Tehri Garhwal in 2010, shows that communities vulnerable to climate change impacts use several strategies to adapt to the changes they perceive[37] (Macchi, 2011). In the case of perceived changes in rainfall (a decrease) and the onset of the monsoon (unpredictability), these include '[r]eplacement of rice with finger millet; purchasing rice; barter; improvising with new (cash) crops; delayed sowing' (Macchi, 2011).

Changes in the hydrological cycle are already affecting the availability of water resources for agriculture in Uttarakhand, leading to crop-water stress in several districts. As discussed in the beginning of this chapter, studies show the impact of climate-related changes on water availability in Uttarakhand. According to INRM's analysis, Pauri Garhwal, a hill district, and Dehradun, a plains district, are the most vulnerable to reduced availability of water resources. This is because of their low seasonal per capita availability of water and their high level of crop-water stress in the winter season (INRM, 2016b). The water-holding capacity of the soil is relatively low in Uttarakhand (below 60 mm), according to the *Atlas on Vulnerability of Indian Agriculture to Climate Change* published by the Central Research Institute for Dryland Agriculture (CRIDA) (Rama Rao et al., 2013). With agriculture estimated to account for over 80% of water usage in Uttarakhand (Kelkar et al., 2008a), and roughly 70% of the population dependant on agriculture and related activities (Planning Commission, GU, 2017, p. 51), the impact of climate change on Uttarakhand's water resources potentially threatens many livelihoods. Some may see no other option than to migrate (see Section 5.2 which discusses the linkages between climate change, agriculture, and migration). However, communities are adapting. In Almora, Bageshwar, and Tehri Garhwal, farmers respond to longer dry spells and drought-like conditions with irrigation systems shared opened on a rotational basis (Macchi, 2011). In Almora, a traditional water-sharing system helps to cope with these impacts (Macchi, 2011).

---

[36] Whereas in the case of Tehri Garhwal environmental factors primarily contribute to the district's 'very high' level of overall vulnerability to climate change (including an increase in night time temperature, floods as well as landslides), socio-economic indicators such as a higher age dependency ratio or the gender gap in literacy rate contribute to this categorisation of Champawat. When just considering the socio-economic indicators, Champawat also ranks first, followed by Bageshwar which is the only other district categorised as having a 'very high' vulnerability to current climate change in this category. When only environmental vulnerability indicators are assessed, Tehri Garhwal is the most vulnerable district, followed by Pauri Garhwal and Champawat.

[37] As discussed elsewhere in this report, records of reliable and long-term meteorological observations are often rather scarce in the western Himalayan region due to a low density of stations combined with poor data quality (Das and Meher 2019). In the Tehri Garhwal district, for instance, the authors of the ICIMOD study could not validate the perceived climatic changes of the communities as they only had data from one weather station and the records also only dated back a few years (Macchi, 2011).

District-wise projected vulnerability profile

Under RCP4.5, all of Uttarakhand's thirteen districts are projected to have increased environmental vulnerability to climate change by the middle of the century (INRM, 2016b). The vulnerability assessment of Uttarakhand districts to projected climate change in the technical report by IRNM is based on a subset of 30 environmental indicators.[38] It is modelled for the years 2050 and 2100 using two different scenarios from the IPPC's *Fifth Assessment Report* (RCP4.5 and RCP8.5). With Almora, Champawat, Haridwar, Pauri Garhwal, and Tehri Garhwal, five districts are projected to have an 'extremely high' vulnerability to climate change under an RCP4.5 scenario by the middle of the century. The authors attribute this increased vulnerability, inter alia, to temperature increases and changes in precipitation patterns[39]. Towards the end of the century, the five districts mentioned before remain in the 'extremely high' category, two districts are projected to have a 'very high' environmental vulnerability to climate change (Chamoli and Dehradun), and three to have a 'high' degree of vulnerability (Nainital, Rudraprayag, Uttarkashi). With Bageshwar and Pithoragarh, only two districts are projected to have a 'moderate' environmental vulnerability towards the end of the century under RCP4.5 (INRM, 2016b).

Under RCP8.5, ten out of Uttarakhand's thirteen districts are projected to have a 'very high' or 'extremely high' environmental vulnerability to climate change (INRM, 2016b). The INRM study, which takes the assessment of current environmental vulnerability to climate change as a baseline, projects that all thirteen districts of Uttarakhand will become more vulnerable towards 2050. By the end of the century, ten out of Uttarakhand's thirteen districts are projected to have a 'very high' or 'extremely high' vulnerability to climate change.[40] Under RCP8.5, therefore, seven out of the ten of Uttarakhand's hill states would have a 'very high' or 'extremely high' environmental vulnerability. Since all plains districts fall under these categories, they may not be a welcoming space for migrants from hill districts.

Water-related stressors are among the most critical factors contributing to vulnerability in several hill districts (Rama Rao et al., 2013)[41]. In CRIDA's 'Atlas on Vulnerability of Indian Agriculture to Climate Change' projected increases in the number of droughts years are listed as factors most contributing to high levels of vulnerability in the hill districts of Bageshwar, Chamoli, and Pithoragarh. In Champawat, projected decrease in rainfall in the month of July is an important factor contributing to vulnerability. Interestingly, in the INRM projection, the vulnerability of water resources under RCP4.5 will increase slightly until 2050, but decrease towards the end of the century (INRM, 2016b). Under RCP8.5, vulnerability is projected to decrease towards 2050 and 2100. The ICIMOD study lists potential future risks from longer dry spells as well as drought-like conditions, leading to health problems and increasing workloads for women and children – resulting in school dropouts (Macchi, 2011).

In some districts, climate change may have positive effects on the agricultural sector. A recent study by the SCCC and the Uttarakhand Forest Department found that climate change might increase crop yields in some districts (SCCC, n.d.). For example, 'higher temperatures allow seasonally longer plant growth for crops in cool and

38 Unlike in the district-wise current vulnerability profile, analyses for projected vulnerability do not include socio-economic indicators. The authors mention methodological challenges ('absence of any reliable projections for the socio-economic indicators'). Therefore, the projected vulnerability assessment for Uttarakhand's districts only assesses 'environmental vulnerability'. A list of the environmental indicators can be found in table A-13 in the appendix of the study (INRM, 2016).

39 For the projected vulnerability profile, socio-economic indicators were not considered in the INRM report.

40 'Very high': Chamoli, Nainital, Udham Singh Nagar, and Uttarkashi; 'extremely high': Almora, Champawat, Dehradun, Haridwar, Pauri Garhwal, Tehri Garhwal.

41 The analysis of the CRIDA report is based on SRES A1B, a scenario from the IPCC Special Report on Emissions Scenario (SRES) published in 2000. The scenario describes 'a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies' in which energy sources are balanced between fossil and non-fossil sources (IPCC, 2000).

mountainous areas that remain at low temperatures for most of the year' (SCCC, n.d.). However, a decline of rice and wheat yields is likely in Chamoli, Pauri Garhwal, Pithoragarh, and Uttarkashi (under both RCP4.5 and RCP8.5). In the report by INRM, climate change-related vulnerability in the agricultural sector is expected to 'marginally decrease' in Uttarakhand's districts towards the mid- and end-century under RCP4.5 (INRM, 2016b). This picture, however, is incomplete as the northern hill districts of Chamoli, Pithoragarh, and Uttarkashi are not included in the assessment[42].

Linking district-wise vulnerability, agriculture and migration

Uttarakhand's climate change vulnerability assessments show that an integrated approach is needed to understand climate-mediated outmigration from hill districts. Most districts face serious challenges from current and projected climate change, which may have several implications for migration. However, while both climate change and migration have been important topics for Uttarakhand's policymakers, they have mainly been treated separately, as discussed in the introductory chapter. Increasing levels of climate change-related vulnerability may drive more people to migrate from hill districts to the industrial centres in the plains. As discussed above, all three plains districts also face increasing levels of vulnerability to climate change – the INRM study assigns them a 'very high' or 'extremely high' environmental vulnerability towards the end of the century under RCP8.5 – so migrants may find themselves living in conditions in which they are equally exposed to the various adverse effects of climate change.

In hill districts, increasing levels of vulnerability to climate change in agriculture contribute to high levels of overall vulnerability to climate change. The hill districts of Champawat and Tehri Garhwal, for example, have a 'very high' vulnerability to current climate change in the agricultural sector in the INRM study and are also the districts the most vulnerable when all the sectors are analysed (INRM, 2016c). Uttarakhand, therefore, faces challenges on many fronts and may lack funds to invest in new income-generation opportunities. Almora and Pauri Garhwal, the other two districts categorised with 'very high' vulnerability when just assessing agricultural indicators, recorded a negative population growth rate between 2001 and 2011. As noted above, people in the hill districts also face increased vulnerability due to water stress. The consequences for agriculture may drive the outmigration of agriculture-dependent populations from hill districts. More data and research are needed to draw conclusions.

A better understanding of the vulnerability of households engaged in agriculture could inform sustainable policies for farmers. The district assessments of climate change-related vulnerability in the agricultural sector help to identify areas most at risk from climate change in Uttarakhand. Large, comparative climate vulnerability assessments, however, are often relatively technical and fail to address people's perceptions, or account for already-existing response mechanisms of individuals or households. Assessments at the household level could help to close this gap. A recent study, for instance, discussed differentiated adaptation strategies of farmers to climate-induced agricultural changes in Uttarakhand (Shukla et al., 2019). Based on household surveys in ten villages, the authors use typology construction to understand why households engaged in farming activities choose diverse adaptation options to secure their livelihoods. They summarise that 'low resourced farmers reported being progressively disengaging with farming as a livelihood option' (Shukla et al., 2019). Based on their findings, the authors suggest

[42] The same districts are also missing for the assessment of climate change-related vulnerability in the agricultural sector under a RCP8.5 scenario in the INRM report which is why it is not included here (INRM, 2016b).

'that the proponents of effective adaptation policies in the Himalayan region need to be cognizant of the nuances within the farming communities to capture the diverse and multiple adaptation needs and constraints of the farming households' (Shukla et al., 2019).

Figure 39 gives a short summary of Section 3.

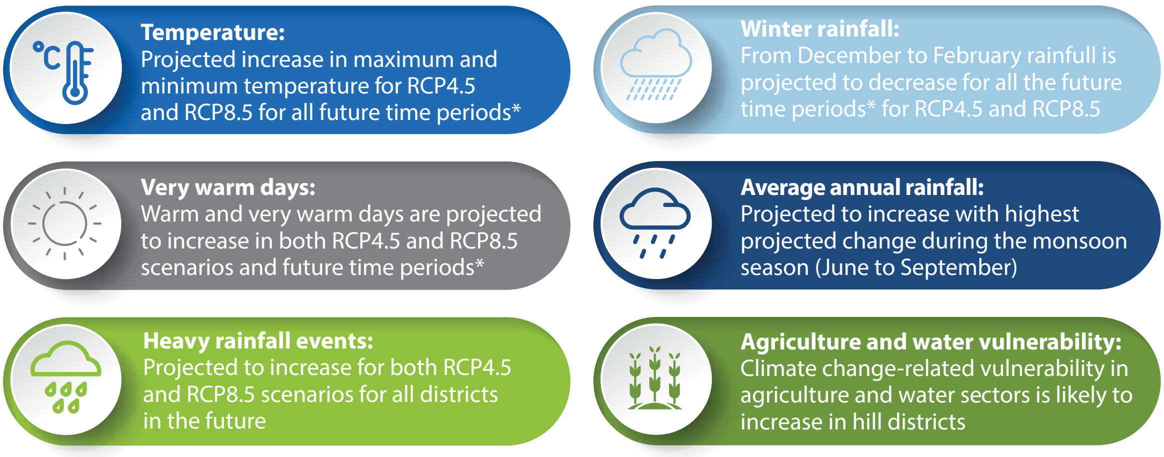


Figure 39: Summary of Section 3; * Future time periods refer to near-future (2021–2050), mid-future (2050–2080) and far-future (2081–2099) scenarios
Figure Credit: Himani Upadhyay, PIK

MIGRATION

Depopulated and empty houses in Almora, Uttarakhand, India.

4 Migration

Migration is the key to understanding the development of Uttarakhand. Historically, migration has significantly affected the hill regions as their mountain communities have used migration as an alternative livelihood and risk-diversification strategy (Gautam and Andersen, 2016; Kassie et al., 2017; Mamgain and Reddy, 2016; Rural Development and Migration Commission, 2018). The following sections synthesize the literature on migration in Uttarakhand.

4.1 Migration and Elevation

Migration in Uttarakhand is correlated with elevation. By correlating the percentage of outmigrants (data from Rural Development and Migration Commission, 2018 and 2011 Census) over the rural population at a development block level (data from Census 2011) with the average elevation of each block (calculated using GTOPO30[43] as digital elevation model), two distinct trends of outmigration emerge. At first, outmigration increases as elevation increases, especially from plains to mountains, but then it decreases at higher elevation (see Figure 40). This difference in trend can be highlighted using the UNEP classification for mountain classes, which helps differentiate between plains, low

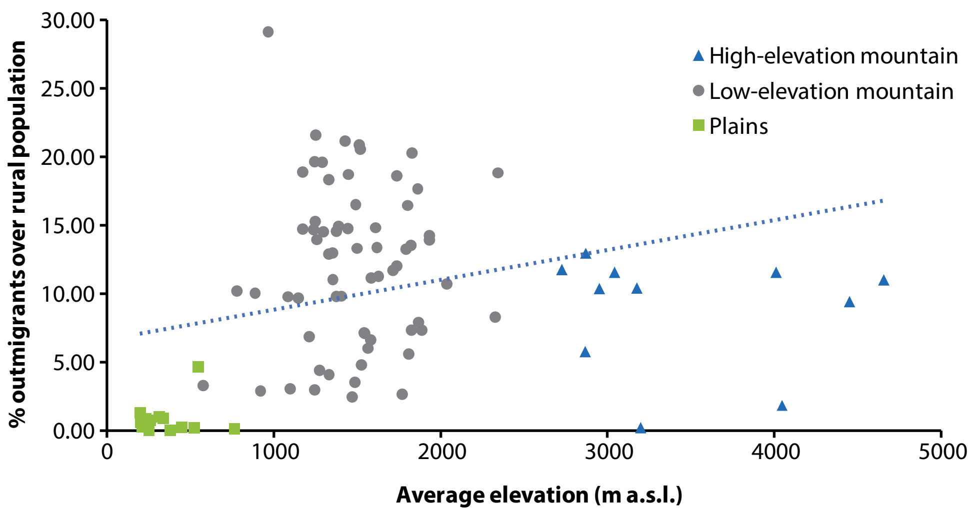


Figure 40: Correlation between percentage of migrants over rural population and average altitude for all the development blocks in the state of Uttarakhand classified as plains, low-elevation mountain, and high-elevation mountain according to the UNEP mountain classes
Image Credit: Riccardo Biella, PIK

[43] GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30, completed in late 1996, was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS)

mountains, and high mountains. High-elevation mountain areas are characterized by elevation higher than 2500 m, low-elevation mountain by elevation between 300 m and 2500 m, while plains by no elevation (Kapos et al., 2000). Below 2500 m of elevation outmigration increases with increasing elevation. Blocks in the low-elevation mountain show significantly more outmigration than blocks in the plains and the blocks in the high-elevation mountain, though this second difference is not as significant. Figure 40 shows the correlation between percentage (%) of outmigration over rural population and average block elevation.

4.2 Migration in Uttarakhand from a Historical Perspective

In Uttarakhand, migration can be traced to the eleventh and twelfth centuries, as people from different parts of India began moving to the hills of Uttarakhand. The hilly jungles were transformed into habitable land (Planning Commission, GU, 2017). Larger waves of outmigration only started in the 1860s, when an increasing number of men left their hometowns to work for the British Indian Army[44] (Pathak et al., 2017, p. 4). This initiated a long tradition of migration of men joining the ranks of the army[45] (Jain and Nagarwalla, 2004; Pathak et al., 2017; Sati, 2016). Migration flows further increased in the 1890s as railways across the Kumaon region provided greater mobility (Pathak et al., 2017). Migration patterns have long been, and still are, instrumental for sustaining livelihoods in Uttarakhand. This pattern was strengthened after Uttarakhand became a state in 2000. As of 2011, the total number of migrants in the state were 4,317,454, with more female migrants at 2,836,147 than male migrants at 1,481,307 (Census, 2011d).

Before statehood, most migrants were men, who would usually leave for some years before eventually returning to their villages (Jain, 2010; Mamgain, 2004, p. 198; Pathak et al., 2017, p. 16). Starting around 2000, however, entire families began to migrate permanently, abandoning their homes and lands in the hills (Planning Commission, GU, 2017). As Deshingkar and Akter explain, improved communications and transport networks, and new economic opportunities in the plains have resulted in unprecedented levels of mobility (Deshingkar and Akter, 2009). This, in turn, has led to gradual depopulation as houses are 'permanently locked' and fields are abandoned (see Figures 41 and 49). Depopulation matters because it is a direct consequence of reduced livelihoods and worsening climatic conditions in the hills and, at the same time, contributes to the hill-plains divide that underlies many socio-economic developments in Uttarakhand. Recognising the intensity and magnitude of outmigration, the government of Uttarakhand constituted a Rural Development and Migration Commission (hereafter referred to as the Migration Commission). In August 2017 this Migration Commission was formed to better understand migration in the state, to develop a vision for rural development, and advise the state government on multi-sectoral development (Rural Development and Migration Commission, 2018).

[44] Outmigration of men accelerated due to the First World War (1914–1918) when young men were recruited by the army and sent off to battlefields in Europe, Asia, and Africa (Pathak et al., 2017, p. 4).

[45] When Uttarakhand was part of Uttar Pradesh, they together had the highest number of army cantonment areas in the country. Jobs in the army were accessible and offered employment in the hill region, which otherwise had very limited job opportunities. Currently, Uttarakhand has the second highest cantonment areas in the country.

Figure 41: Abandoned agricultural field in Pauri Garhwal district (on the left) and Almora district (on the right), in Uttarakhand
Image Credit: Himani Upadhyay, PIK, captured in October 2019

4.3 Reasons for Migration

The primary reasons for migrating in Uttarakhand include limited income-earning opportunities in the agricultural sector and a general inability to diversify livelihoods in the hills (Hoffmann et al., 2019; Jain, 2010; Mamgain and Reddy, 2016; Rural Development and Migration Commission, 2018; Tiwari and Joshi, 2016). For example, according to data collected by the Migration Commission, migration is linked to insufficient employment opportunities in rural areas (see Figure 42) (Rural Development and Migration Commission, 2018). A study produced in 2010 by ICIMOD on migration drivers also identified lack of livelihoods (90% of respondents), coupled with waning interest in agriculture (43%), as the main reasons for migration (Jain, 2010). Low agricultural productivity also appears to be an important push factor. Declines in land productivity and crop yields contribute directly to migration within the state. This underscores the nexus between climate impacts, livelihoods, and migration. A field survey of 4,000 respondents conducted by Tiwari and Joshi confirms this. They found that migration is linked not only to limited livelihoods (27% of respondents), and declining agricultural productivity (21%) but also to extreme weather events and natural disasters (11%) (Tiwari and Joshi, 2016).

There are other reasons for migration in Uttarakhand. Figure 42 shows that dearth of educational (15.12%), health (8.83%), and infrastructural (3.74%) facilities account for almost one-fourth of the migration in the state (Rural Development and Migration Commission, 2018). Crop depredation by animals like wild boars and monkeys has a direct bearing on farm income and sustenance and accounts for migration (5.61%). Further decline in land productivity and decline in crop yields also contribute to outmigration in the state (5.44%). Lastly, some people migrate to emulate other family members (2.52%) (Rural Development and Migration Commission, 2018).

Geophysical constraints of the mountains have been intervening factors for migration. Jodha (1992) refers to these constraints as 'mountain specificities', which are conditions characterising mountain areas. These specificities are 'inaccessibility, fragility, and marginality' (Jodha, 1992, p. 44). Inaccessibility is due to slope, altitude, terrain, and periodic seasonal hazards. It manifests in isolation, scattered habitation, limited links to the outside world, and poor communication (Jodha, 1992, p. 44), which in turn affect the activity and livelihood patterns of the population. Fragility refers to limited capacity of mountain areas to 'withstand even a small degree of disturbance' (Jodha, 1992, p. 45), which can thereby have cascading impacts on mountain resources, environment, and livelihoods. Both inaccessibility and fragility results in marginality or exclusion from participating in 'mainstream pattern of activities' (Jodha, 1992, p. 45), which leads to unfavourable terms of trade to such locations. These specific geographical and regional characteristics can lead to low economic opportunities, environmental degradation, and livelihood insecurity, all of which can lead to migration (GU, 2018).

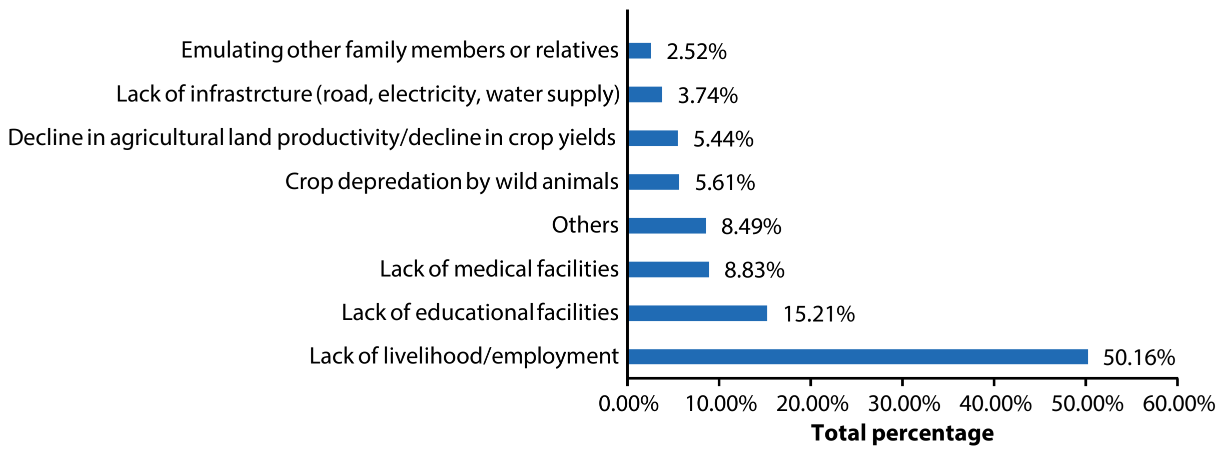


Figure 42: Reasons for migration
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

4.4 Migrant Destinations: Intra-district Versus Intra-state Mobility

The bulk of migration in Uttarakhand takes place across short distances, with roughly 70% of migrants moving within the state (Rural Development and Migration Commission, 2018) (see Figure 43). According to the Migration Commission, people in Uttarakhand migrated to the following destinations (see Table 7):

- Inter-district (from one district to another): 35.69%
- Intra-district (within the same district)
  - To nearby towns: 19.46%
  - To district headquarters: 15.18%
- Inter-state migration: 28.72%
- International migration: 0.96%

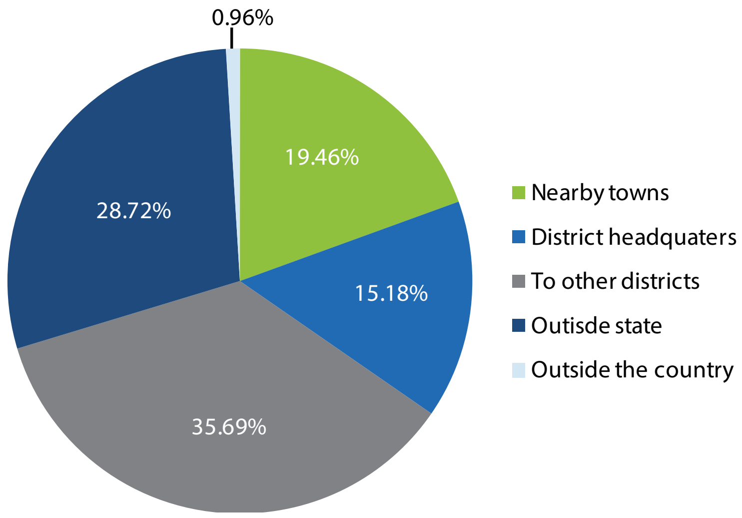


Figure 43: Reasons for migration
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

Urban centres are important migrant destinations. The districts of Dehradun, Haridwar, and Nainital have a higher level of economic growth and urbanisation and attract the highest percentage of migrants (Rural Development and Migration Commission, 2018). The Uttarkashi district, although not as urbanised, is the destination to approximately 39% of migrants.

Table 7: District-wise migration destinations (%)

District	To Nearby Towns (%)	To District Headquarters (%)	To Other Districts (%)	Outside State (%)	Outside Country (%)
Uttarkashi	39.14	20.27	22.37	17.34	0.89
Chamoli	19.79	13.34	50.48	15.88	0.51
Rudraprayag	19.34	12.66	40.51	25.69	1.8
Tehri Garhwal	17.73	9.42	40.78	28.98	3.09
Dehradun	57.12	23.67	8.08	10.46	0.67
Pauri Garhwal	19.61	9.55	36.15	34.15	0.54
Pithoragarh	15.7	33.07	34.33	16.67	0.23
Bageshwar	15.45	22	37.19	25.18	0.19
Almora	7.13	13	32.37	47.08	0.43
Champawat	14	16.86	36.24	32.59	0.3
Nainital	35.49	17.93	21.47	24.64	0.47
Udham Singh Nagar	27.48	8.48	28.04	31.11	4.89
Haridwar	44.27	18.29	16.1	20.85	0.49

Source: Rural Development and Migration Commission, 2018

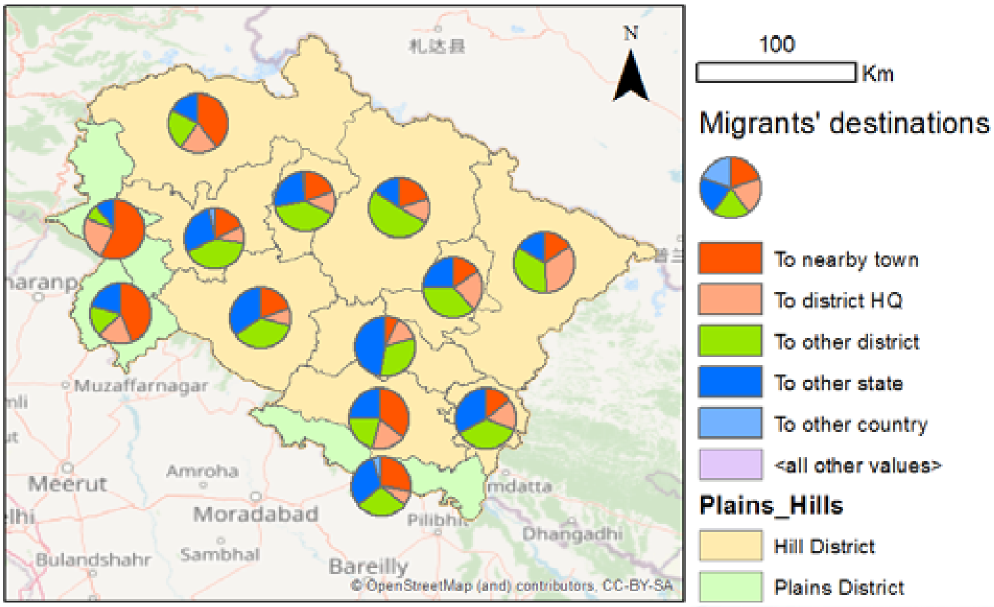


Figure 44: Migrants destination by district
Data Source: Rural Development and Migration Commission, 2018
Image Credit: Riccardo Biella, PIK

4.5 Age Profile of Migrants

The propensity to migrate tends to decrease with age. The young migrate more frequently than the middle-aged or elderly (Boneva and Frieze, 2001; Frieze et al., 2006). This is probably because the expected benefits are inversely correlated to age: individuals who expect a high return from migration will migrate as soon as possible (Becker and Morrison, 1997). Migration data from Uttarakhand shows that 42% of migrants are between the ages of 26 and 35 years, 29% are over 35 years of age, and another 29% are 25 years of age or under (see Figure 45). For district-wise spread, see Figure 46.

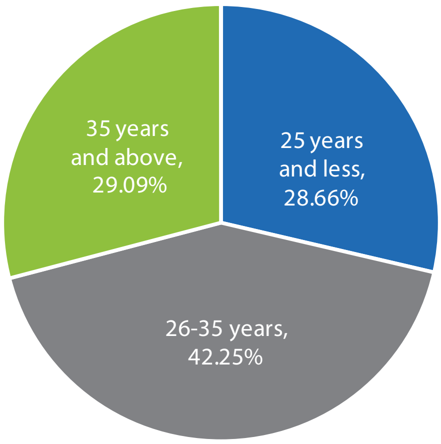


Figure 45: Age-wise migration particulars of Uttarakhand
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

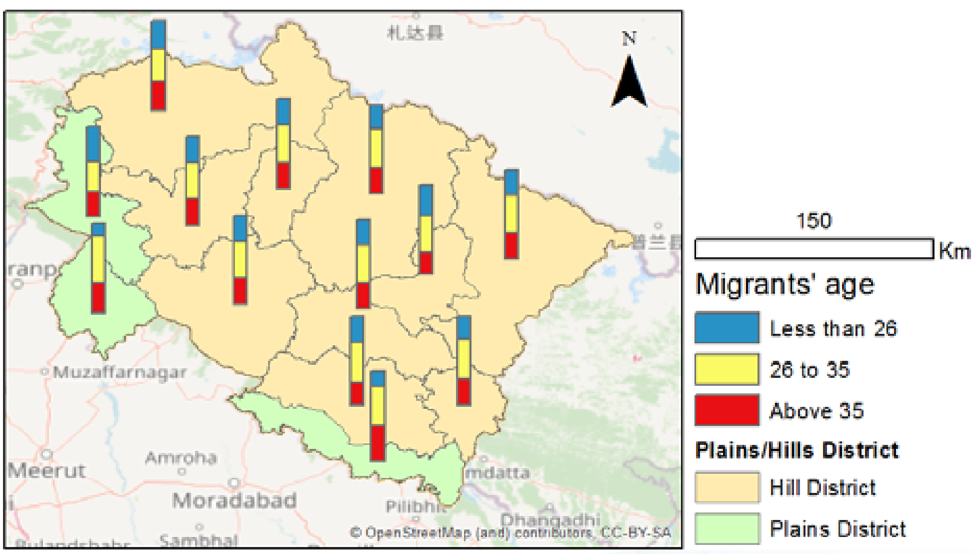


Figure 46: Migrant's age by district
Data Source: Rural Development and Migration Commission, 2018
Image Credit: Riccardo Biella, PIK

4.6 Uninhabited Villages and Depopulation

Because of migration, an increasing number of villages in Uttarakhand are uninhabited. The 2011 Census and the Migration Commission's 2018 survey help document this phenomenon. According to the Population Census, 1,048 out of 16,793 villages in Uttarakhand were uninhabited in 2011 (Census, 2011a). These uninhabited villages constituted 6.24% of all revenue villages[46]. The Migration Commission's Depopulation has continued unabated since the 2011 Census: according to the survey undertaken by the Migration Commission in 2018, 734 villages in the state have become uninhabited since 2011 (Rural Development and Migration Commission, 2018, p. 52). These villages are spread across all thirteen districts (see Figure 47) (Rural Development and Migration Commission, 2018), and are often referred to as 'ghost villages' (Press Trust of India, 2018; Upadhyay, 2018; Venkatesh, 2016).

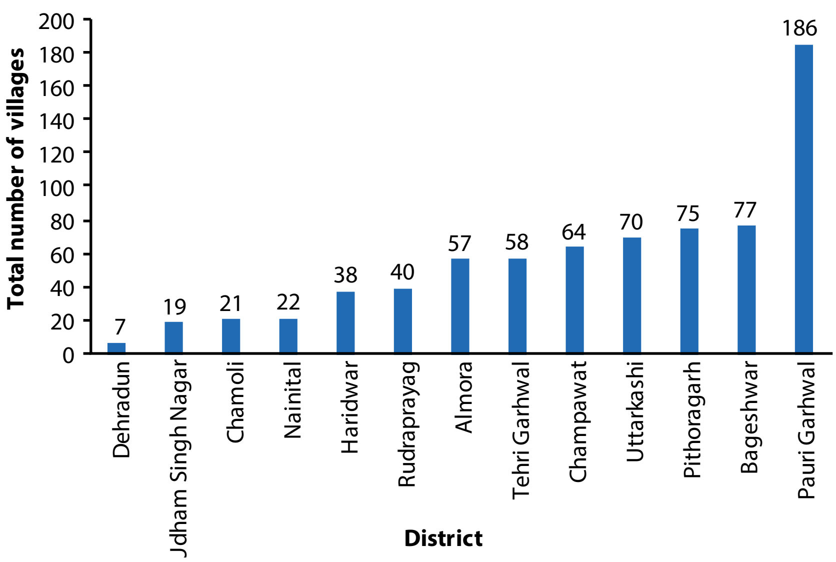


Figure 47: District-wise number of inhabited villages (depopulated after 2011)
Data Source: Rural Development and Migration Commission, 2018

Though depopulation has occurred across all districts of Uttarakhand, it is more pronounced in the hill than in the plain districts (see Figure 48 which shows the distribution of outmigrations as percentage of the district population as reported in the interim report of the status of migration) (Rural Development and Migration Commission, 2018, pp. 28–33).

[46] Revenue village is a concept introduced during British Indian Administration. It was designed for revenue collection process and was not meant for village planning and development. In the rural areas, the smallest area of habitation, viz., the village generally follows the limits of a revenue village. One revenue village may contain many hamlets. The entire revenue village is one unit. Each revenue village has a definite surveyed boundary and each village is a separate administrative unit with separate village accounts (Source: Census, 2011e; Ramachandraiah, 1995).

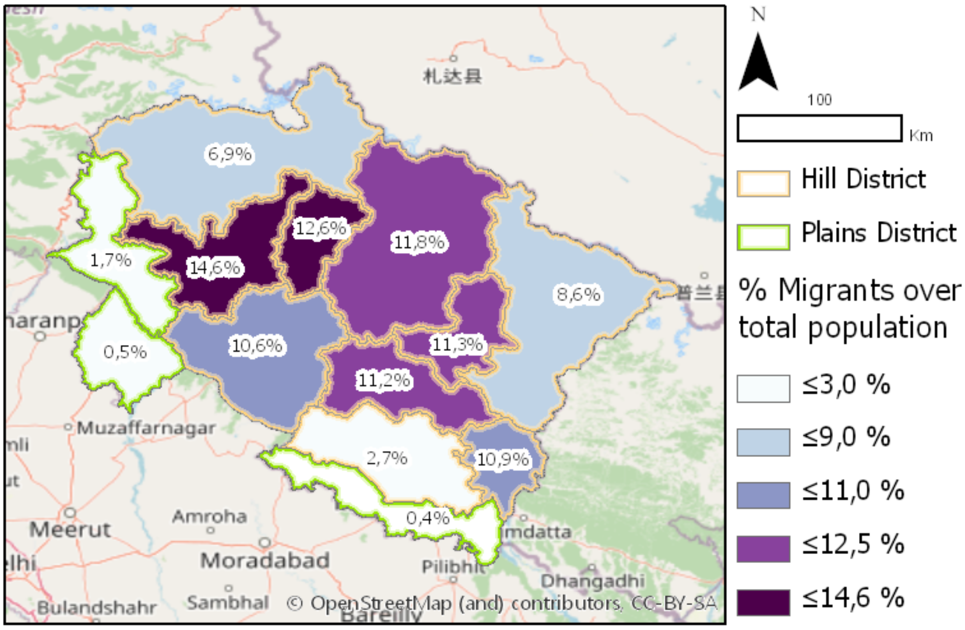


Figure 48: Percentage of out-migrant over the total population by district
Data Source: Rural Development and Migration Commission, 2018; Census 2011
Image Credit: Riccardo, Biella, PIK

The Migration Commission found that uninhabited villages lack one or more of the following services: 1) road connections, 2) electric power transmission, 3) access to drinking water within 1 km radius, and 4) availability of a primary health centre (Table 8). Simply put, depopulation is closely linked to the lack of crucial infrastructure

Figure 49: Abandoned houses in Pauri Garhwal district, Uttarakhand
Image Credit: Himani Upadhyay, PIK, Captured in October 2019

and services in the hill districts. Of the 734 villages that have depopulated since 2011, 660 lacked a primary health centre; 482 were without any road connectivity; 399 were without drinking water within 1 km radius, and 358 were not electrified. Figure 49 shows abandoned houses in Pauri Garhwal district. Table 8 lists some of the characteristics of depopulated villages after 2011, according to the data collected by the Migration Commission.

Table 8: Revenue villages/hamlets/toks depopulated after 2011 and their characteristics

District	Uninhabited villages/ hamlets/toks (after 2011)	Villages/ hamlets/toks without road connectivity	Villages/ hamlets/ toks not electrified	Villages/hamlets/toks without drinking water within 1 km radius	Villages/ hamlets/toks without primary health centre
Uttarkashi	70	38	17	30	56
Chamoli	41	33	35	26	41
Rudraprayag	20	14	5	7	17
Tehri Garhwal	58	44	33	33	58
Dehradun	7	3	5	5	7
Pauri Garhwal	186	126	84	97	164
Pithoragarh	75	44	53	45	74
Bageshwar	77	39	27	49	62
Almora	57	42	21	30	53
Champawat	64	56	43	32	61
Nainital	22	15	10	10	20
Udham Singh Nagar	19	13	5	15	19
Haridwar	38	15	20	20	28
Uttarakhand	734	482	358	399	660

In some districts, the population shrunk by almost 50% (see Figure 50). More specifically, according to the Migration Commission data, the population in 565 villages has halved since 2011.

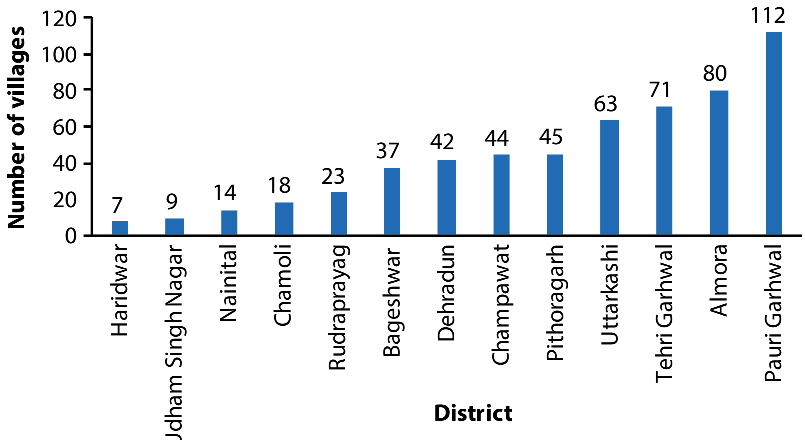


Figure 50: District-wise number of villages where population reduced by 50% after 2011
Data Source: Rural Development and Migration Commission, 2018
Figure Credit: Himani Upadhyay, PIK

4.7 Outcomes of Migration

Gendered effects

Female migration has increased over the years. Female migration has increased over the years. The 2011 Census sheds light on the increasing number of female migrant workers. The number of migrants in Uttarakhand was 4.3 million approximately of which number of female migrants were higher (2.8 million approximately) as compared to male migrants (1.5 million approximately) (Census, 2011).

Figure 51: Woman carrying fodder (on the left), and woman engaged in a post-harvest process (on the right), Almora district, Uttarakhand
Image Credit: by Himani Upadhyay, PIK, captured in November 2019

When men migrate, however, women who stay behind in the hills are presented with more opportunities as well as more responsibilities. On one hand, women take on additional agricultural functions ('feminisation of agriculture') besides routine household chores, which include collection of fuel wood from forest, bee keeping, poultry, fodder for the animals, fetching water, cooking, cleaning and looking after elderly and children (see Figure 51) (Agarwal, 2010; Maithani, 1996). And climate change-related resource depletion has added to the workload of women where they have to dedicate more time managing risks and resources (Bhandari and Reddy, 2015; GU, 2014; Sherpa, 2007). It is these conditions that have allowed women to become 'primary resource developers' (Tiwari and Joshi, 2016, p. 331). Male migration in Uttarakhand has not only benefitted the rural economy through remittances; it has also indirectly contributed to women's empowerment by improving women's access to education, development opportunities, leadership, decision-making power and natural resource management.

Women's coping mechanisms have adjusted to the effects of evolving climate conditions on agriculture. A survey of ten villages of the Upper Kosi Catchment conducted by Tiwari and Joshi documents that women have developed several adaptation measures[47] to maintain a minimum level of agricultural productivity despite declining total rainfall and the number of rainy days (Tiwari and Joshi, 2016). The positive implications for women resulting from the migration of men help explain the higher Gender Development Index (GDI) in hill districts, as discussed in Section 2.2. However, more research is needed to understand these dynamics better.

Transition to off-farm activities

An important outcome of migration is the population's transition from farming to off-farm occupations. A study comparing occupation before and after migration notes that before migration most migrants were engaged in the primary sector (agriculture and allied activities). After migration, most worked in the tertiary sector (hotels, government jobs, shops, etc.) (Hoffmann et al., 2019). Similarly, data collected from 951 households across six districts of Uttarakhand provides evidence for a change in the socio-economic dynamics in rural mountain communities from small-scale subsistence level farmers to off-farm migrant workers (Naudiyal et al., 2019). Migration comes with substantive transformations in the occupation of the population. The loss of the agricultural labour force and resulting increase in the tertiary sector workforce are part of a socio-economic loop that underlies the current and probable future development of the state.

Remittances

Remittances have been integral to the socio-economic development of Uttarakhand. The state became renowned for its 'money order economy', namely for remittances sent back by migrants via postal money orders (Dhyani, 1994). Declining subsistence agriculture has compelled hill communities to diversify income sources and rely increasingly on cash-based economies (Mehta, 2014). The HDR 2018 Survey[48] reveals that 75.5% of migrants remitted money – most often on a monthly basis (42%) – to their place of origin (GU, 2018). In the hill districts of Champawat, Chamoli and Rudraprayag, as well as the plain districts of Dehradun and Haridwar, the proportion was even higher, at around 80% or more. Nevertheless, the impact of remittances on local economies remains disputed. Majority of the remittance are used for daily household consumption needs like food and clothing, followed by education and health expenses and a meagre amount is used for paying agricultural labour and other costs relating to agriculture (Jain, 2010; Mamgain and Reddy, 2016). And therefore despite a steady monetary flow, remittances have not generated a cascading effect to transform the local village economy as it has in other states like Kerala and

[47] The study lists adaptation measures being used by rural women: '27% women replenished their water sources through using water-conserving forestry and horticultural practices; similarly 19% women households cultivated crops which are drought resistant or less water intensive; 25% women cultivators sustainably managed depleting water resources by evolving and practicing locally effective rainwater collecting measures based on traditional water resource management system; 21% women-headed households altered traditional cropping patterns and adjusted crop rotation; In order to increase food production under rainfall uncertainty conditions women households (11%) cultivated abandoned agricultural land'(Tiwari and Joshi, 2016, p. 343).

[48] The survey covered 8450 households. The total population for the sample was 2,482,333.

Bihar (Deshingkar and Farrington, 2009). It appears that remittances did not lead to higher capital formation, nor were they invested in agriculture. More research on the impact of remittances on agriculture is therefore necessary to understand their apparently limited effectiveness in the context of Uttarakhand.

The literature on migration in Uttarakhand delineates a complex picture of the multiple factors affecting the socio-economic development of the state. Changing climatic conditions, such as erratic temperatures, changing cropping seasons and the resulting loss in productivity, partially explain the steady flow of migrants towards urban centres. In turn, the gradual shift from agricultural to third-sector employment has exacerbated the hills-plains divide. While the economy is developing and diversifying in the main urban centres, the hill districts have suffered in terms of access to resources and services. This account of growing isolation and destitution experienced by the hill population exemplifies many of the predicaments associated with climate change. Improved gender indicators, as well as remittances, highlight possibly positive aspects of such transformations; but the adverse socio-economic impacts of a changing climate, among other social, economic and political factors, are both undisputed and long-term. The relationship between climate change and migration is discussed in more detail in the next section. Figure 52 gives a summary of the key points discussed in this section.

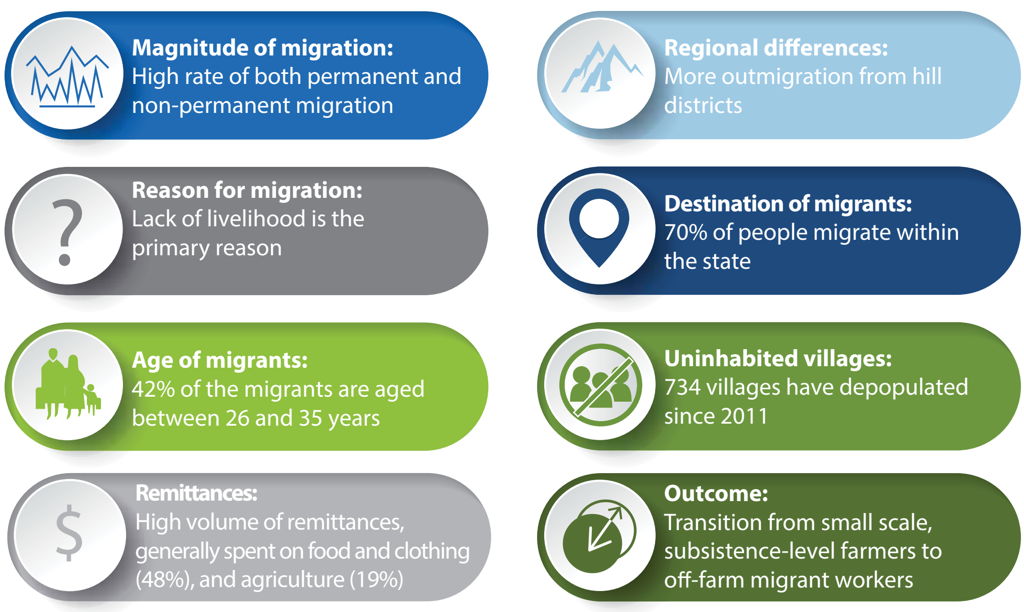


Figure 52: Uttarakhand migration overview
Data Source: Census, 2011; Rural Development and Migration Commission, 2018; Jain 2010
Figure Credit: Himani Upadhyay, PIK

CLIMATE CHANGE AND MIGRATION

Man ploughing his fields in Uttarakhand India.

© Shutterstock/ Daniel Prudek

5 Climate Change and Migration

Linkages between climate change and migration are complex (White, 2011), but understanding them has a crucial bearing on science, policy and society (Piguet, 2010; Warner et al., 2010). There is little policy or research consensus on how many people will be forced to move because of climate change, but there is general agreement that it will significantly impact existing migration patterns and that developing countries will be the most affected (ADB, 2009; Foresight, 2011a; Rigaud et al., 2018). In climate change impact research, migration was noted as early as 1990 by the IPCC, which emphasized that '[t]he gravest effects of climate change may be those on human migration as millions are displaced by shoreline erosion, coastal flooding and severe drought' (IPCC, 1990:103). The IPCC added that 'people may decide to migrate in any of the following cases: loss of housing [...], loss of living resources [...], loss of social and cultural resources [...]' (IPCC, 1990b, p. 5–9). The topic has gained momentum in academic research since 2011, when the Foresight Report[49] presented a comprehensive assessment of the existing evidence on linkages between climate change and migration. The report noted that climate change will impact existing migration processes, and that understanding the links between migration and environmental changes is of particular importance for certain key ecological regions including mountain areas (Foresight, 2011b, p. 11). In December 2018 – the Global Compact for Safe, Orderly and Regular Migration (GCM) was adopted by 152 countries, including India. This internationally negotiated document on migration acknowledged that 'migration movements may result from adverse impacts of climate change' (United Nations, 2018, p. 10/36).

Climate change can influence already existing population movements. Climate change can manifest itself through slow and gradual changes like rising temperatures, altered rainfall patterns, droughts, sea level rise, and coastal erosion. Impacts can also be sudden and disruptive like floods, cyclones and river erosion. Both types of change can influence migration in different ways. Sudden, extreme changes may cause affected populations to leave their homes at least temporarily, causing large-scale movements, but where return is often feasible. Conversely, gradual changes may lead to a deterioration of environmental, socio-economic and socio-cultural conditions which – given the irreversible effects of these processes – can lead to more permanent migration. When, why and how people migrate under changing climatic conditions are complex questions. Even in cases where the environment is a predominant driver of migration, it is usually compounded by social, economic, political, cultural and other factors (Black et al., 2011; Foresight, 2011a; Siddiqui et al., 2019). Figure 53 depicts the complex contextual drivers that can lead to migration. Climate change can affect these by impacting, for example, farm-based livelihoods, rural wages, agricultural prices, exposure to hazards and ecosystem services. But the presence of such migration drivers

[49] Commissioned by the UK's Government Office of Science, the report aimed at assessing the best available science and evidence to develop a vision for how human population movements across the world could be affected by global environmental changes between now and 2060, with a focus on the diverse challenges and opportunities for migrants, populations and policymakers in originating and receiving regions

does not mean migration will necessarily occur: that depends on many intervening factors along with personal and household characteristics. The report also notes that 'climate change is equally likely to prevent migration as it is to cause migration' (Foresight, 2011b, p. 12). Climate change might have a deleterious effect on, say, agricultural productivity, yet by eroding important assets it may reduce affected households' capability to afford the costs of migration, thus rendering them more vulnerable.

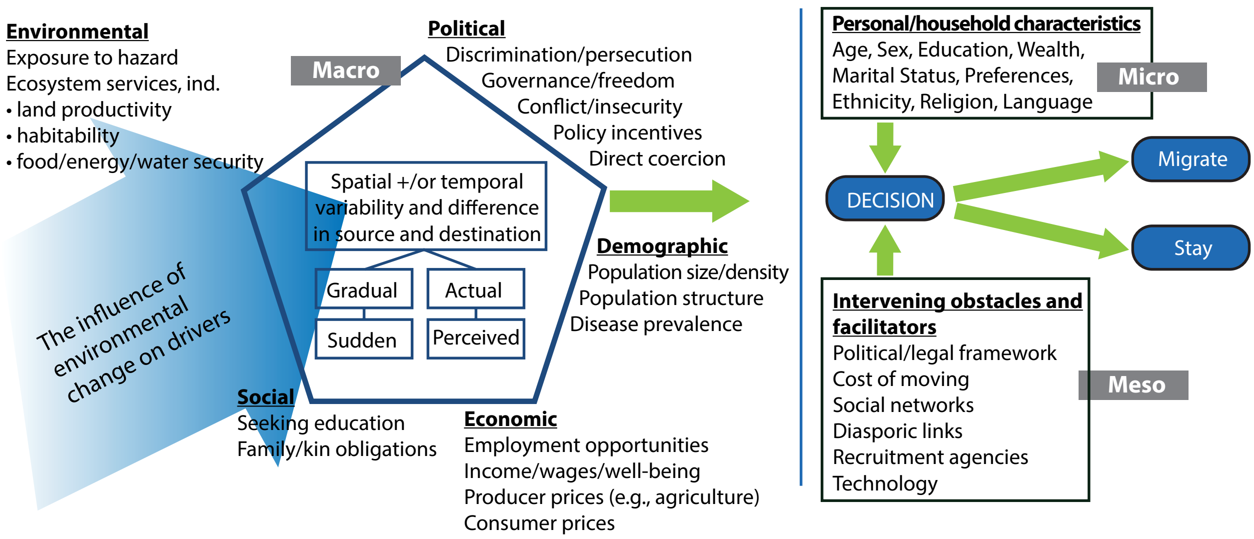


Figure 53: Conceptual framework showing drivers of migration and the influence of environmental change
Data Source: Foresight Report 2011

Migration is one of the strategies of rural households to reduce their vulnerability to climate change (McLeman and Smit, 2006). However, migration comes with risks and costs, such that vulnerability may not be reduced when people move from rural to urban areas (Jacobson et al., 2018). For example, those migrating from rural areas threatened by climate change may settle on urban floodplains, where their vulnerability may even be greater because of poor living or working conditions, lack of access to basic amenities, discrimination, loss of identity, and psychosocial stress, among others (Banerjee et al., 2018). Similarly, the community migrants have left can become more vulnerable through reliance on insecure remittances and a declining labour supply (Wise and Covarrubias, 2009). Refer to Section 3.5 on district-wise vulnerability to climate change and its impacts in Uttarakhand.

5.1 Cumulative Impacts of Climate Change

How does climate change influence migration in the state of Uttarakhand? In a state where 71% of the population is dependent on rain-fed agriculture, climate change's cumulative impacts on water availability and agricultural productivity can cause a cascading effect on local livelihoods that may in the future contribute to migration (see Figure 54). Scientific studies have shown that changes in precipitation and temperature are likely to affect the volume, discharge and availability of water in Uttarakhand (Bandyopadhyay and Perveen, 2003; Kumar et al., 2006; Negi et al., 2012; Viviroli et al., 2007, 2003) (see Chapter 3). Glacier retreat and snow cover changes have contributed to a localized decline in agricultural yields and affected water availability in higher mountain regions of the Himalayas (IPCC, 2019; Rasul et al., 2019). Changing climatic conditions can also lead to more frequent droughts, greater incidence of high-intensity rainfall, increased number of dry days and more frequent floods (GU, 2014; Krishnan et al., 2019; Tewari et al., 2017). Section 3 of this report discusses how maximum and minimum temperatures are projected to increase, while rainfall is projected to both increase and decrease: more annual rainfall and heavy rainfall events as well as reduced winter rainfall. Extremes like warm and very warm days are also projected to increase for RCP4.5 and RCP8.5 (as discussed in Section 3). All these have implications for migration (IPCC, 2019).

Figure 54 shows the linkages between different aspects of climate change, its direct impacts on agriculture and water resources and the impacts of these, which include outmigration. However, it can be difficult to distinguish between climatic and non-climatic drivers as they interact to produce different mobility outcomes. Despite the close relationship between these factors, distinguishing the impacts of climate change on migration patterns distinctly from other factors is challenging (Black et al., 2011, 2008; Boas et al., 2019, p. 902; Foresight, 2011b; Kniveton et al., 2008).

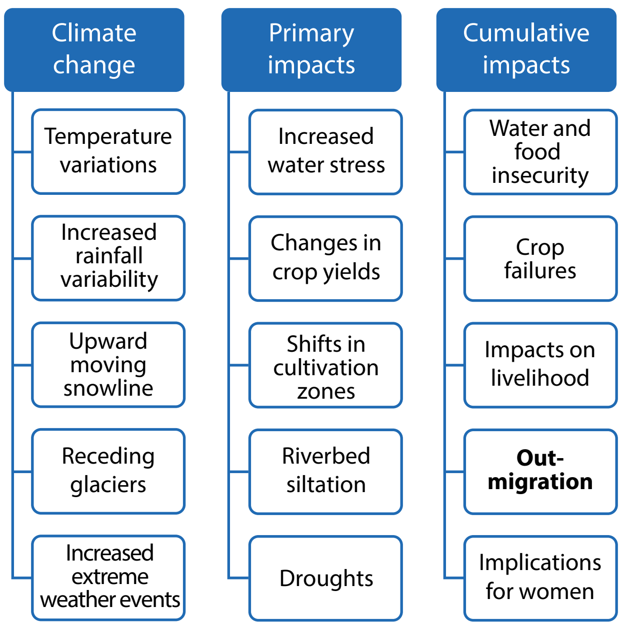


Figure 54: Climate change and migration linkages in Uttarakhand
Figure Credit: Himani Upadhyay, PIK

5.2 Climate Change, Agriculture and Migration

Agriculture is the link between climate change and migration in Uttarakhand. In developing countries, largely dependent on climate-sensitive economic activities such as agriculture, changing climatic conditions and climate extremes may accelerate migration (McLeman and Hunter, 2010). Falco, using data from 108 countries, shows how agriculture is the main link between climate change and migration (Falco et al., 2019). A similar study for India shows how weather variability can influence migration via the agriculture tunnel (Kavi Kumar and Viswanathan, 2013, p. 8). Studies of Uttarakhand also document that decreasing agricultural productivity is a major reason for migration in the state (Hoermann et al., 2010; Joshi, 2018; Mamgain and Reddy, 2016; Tiwari and Joshi, 2016, 2015).

Agricultural productivity is declining for many reasons. Rain-fed subsistence agriculture is the mainstay of the Uttarakhand's hill communities, which makes them heavily dependent on natural resources like land, forest and monsoon rain. These communities have been self-sufficient in food production, but in recent years agricultural productivity has declined and many households have become unable to fulfil their own food needs (Naudiyal et al., 2019). The reasons for this include a decrease in per capita land holdings, erratic rainfall, water stress, lack of irrigation infrastructure, crop depredation by animals like wild boars, monkeys, etc., and a waning interest in farming amongst the youth (Bhandari and Reddy, 2015; Jain, 2010; Mamgain and Reddy, 2016; Rural Development and Migration Commission, 2018; Shukla et al., 2018).

The geography of Uttarakhand affects land availability and agriculture. Only 14% of the state is arable land (GU, 2019). A minimum of 0.2 hectare of arable land per person is necessary to practice sustainable agriculture in Himalayas (Tiwari and Joshi, 2015). However, in mountainous parts of Uttarakhand, the average availability of cultivated land is merely 0.16 hectare/person. Approximately 87% of households have a landholding size of less than 1 hectare. These small landholdings in the hills are unsustainable both in terms of productivity and food security (Kuniyal, 2003; Sati, 2005). By contrast, agricultural productivity in the plains districts of Haridwar, Dehradun, Udham Singh Nagar and Nainital is higher than the hill districts (SCCC, n.d.). This is partly due to better soil conditions in the plains and partly due to lack of access to improved technologies like machinery, seed quality and agriculture extension services in the hills (SCCC, n.d., p. 2). In addition to small landholdings, access to irrigation is a problem in hill districts. Of the states' 13 districts, only 4 have 50% of the net sown area is under irrigation (Planning Commission, GU, 2017). Only 10% of the total cultivated area in the hill districts is currently irrigated in the state. Although expensive to install and maintain, lift irrigation systems could improve conditions in the mountains, as shown in the neighbouring Himachal Pradesh (Government of Himachal Pradesh, 2002, p. 32). In many areas, mountain springs continue to provide the only source of water but are now drying due to climate change (Agarwal et al., 2012; Tambe et al., 2012).

These pressures have translated into the declining agricultural sector. The 2017 economic survey by the state's Directorate of Economics and Statistics reports that the contribution of the primary sector (agriculture and allied services) to Uttarakhand's GDP has dropped from 14% in financial year 2011–12 to approximately 10% in 2017–18 (Rural Development and Migration Commission, 2018). Statistics indicate that the area under food grain cultivation went from 970.14 thousand hectares in 2005–06 to 883.93 thousand hectares in 2014–15 (Planning Commission, GU, 2017).

Climate change causes multiple stressors to an already deteriorating agricultural sector. Uttarakhand has a long tradition of a subsistence economy, with mixed farming of crop and animal husbandry, being practised by 70% of its population (Maikhuri et al., 2013, 2001, 1997; Semwal et al., 2004). Although hill agriculture has never been highly productive (Naudiyal et al., 2019; Shukla et al., 2018; Sunderesan et al., 2014) it has been integral to hill life. However, in the past two decades further decline in agricultural productivity – for which change in climatic conditions is emerging as a key reason – has added to the farm stress of the hill farmers and has contributed to outmigration (Wester et al., 2019). Isaac and Isaac, while assessing the impacts of climate change on agriculture in Uttarakhand, show that from 2004 to 2009, low rainfall and uneven spatial distribution led to a decrease in the wheat yield. During the same time, paddy crop also showed a decrease in yield due to insufficient rainfall at the time of transplantation on the one hand and the other hand high loss of top productive soil due to an increase in the amount and intensity of rainfall (Isaac and Isaac, 2017). They also elaborate on how frequent droughts and low crop production have been observed in various districts of Uttarakhand due to uneven spatial and temporal variation in rainfall. As discussed in Section 3.3 (on monsoons), although rainfall has not declined during the monsoon season, the number of rainy days have, implying that the intensity of rainfall has increased. Such high-intensity rainfall events can cause crop losses as standing crop ready for harvest can be destroyed. It is also highlighted in the section that a decrease in total production is seen at more at higher altitudes (hill districts) as compared to the plains.

Similarly, another study on impacts of climatic components for rice-wheat cropping system showed that the higher mean, maximum and minimum temperatures during the winter season have resulted in poor yields of wheat, while lower mean, maximum and minimum temperatures resulted in poor yield of rice in the Western Himalayan region (BAIF, 2011). A report of the Indian Government's Indian Network on Climate Change Assessment[50] (INCCA, 2010) discusses how, with increasing temperatures, the agriculture line may shift to a higher altitude in the Indian Himalayan Region (IHR). As that happens, the areas which were pastures for animal grazing would reduce as the pasturelands get converted to cultivable land. This would reduce the availability of fodder for livestock (INCCA, 2010). There are other studies which report evidence on changes in the time of flowering and fruiting of plants, pest infestations, shifting of cultivation zones of apple and other crops, increased intensity and frequency of flash floods, drying up of perennial streams, and animal attacks (Bhatt et al., 2000; Hasnain, 2002; Kuniyal, 2002). Increased pest infestation due to increased temperatures, depleted soil moisture and elevated CO_2 levels are also observed in Uttarakhand (Rautela and Karki, 2015, p. 402).

Similarly, in the horticulture sector, the decline in snowfall is already impacting crops like apple, which are showing a decline in production and areal coverage (DST, 2019a). Climate change has increased the vulnerability of an already fragile hill ecosystem (Sharma, 2015). In addition to direct impacts of climate change, other impacts like changes mainly in socio-economic structures, land use, the interaction between the environment and genetic resources, i.e. agrobiodiversity[51] have led to a decline in traditional agricultural systems of the region (Ravera et al., 2016). Changes in climate may further increase the rate of erosion in agrobiodiversity and also affect the quality as well as quantity of yields of traditional farming systems in the region (Maikhuri, 2012). The combined effect of increasing temperature, rainfall, runoff, and urbanisation have impacted agriculture patterns and the subsistence economy. Though farmers respond to changes in rainfall by shifting to less water-intensive crops and diversifying their sources of livelihood (Kelkar et al., 2008b), the intensity and speed of change have rendered this ineffective as they cannot cope with the pace of change. While communities in Uttarakhand are actively adapting by replacing crops and shifting to smaller livestock, there is a future risk of increased insecurity in food and livelihoods (Macchi, 2011; Macchi et al., 2015).

---

[50] Indian Network for Climate Change Assessment (INCCA) was a network-based programme of the Ministry of Environment, Forest and Climate Change, which consisted of over 120 institutions and over 250 scientists countrywide. The report provides an assessment of the impact of climate change in 2030s on four key sectors, namely Agriculture, Water, Natural Ecosystems & Biodiversity and Health in four climate-sensitive regions of India, namely the Himalayan region, the Western Ghats, the Coastal Area and the North-East Region.

[51] Agrobiodiversity is the result of the interaction between the environment, genetic resources and management systems and practices used by culturally diverse peoples, and therefore land and water resources are used for production in different ways.
Source: http://www.fao.org/3/y5609e/y5609e01.htm.

Communities are observing and experiencing the impacts of climate change on agriculture. A field survey done by Jain (2010) highlights that communities have been experiencing not only extreme precipitation events during the rainy season (commonly referred to as cloudbursts) but also a reduction in the overall number of rainy days (Jain, 2010). For the winter season, a decline in rainfall was noted. Changes in winter rainfall have direct consequences for Rabi crops. Similarly, Macchi's (2011) vulnerability and capacity analysis (VCA) on perceptions of climate change showed that communities are already experiencing changes like a decrease in rainfall, an unpredictable onset of the monsoon, prolonged dry spells with drought-like conditions, higher temperatures linked with decreased water availability and warmer winters with less snowfall (Macchi, 2011). All these changes have a direct impact on agriculture systems, e.g. decline in agricultural productivity, drier streams, less productive lands, and increased incidence of pests and disease. A study done in the Upper Kosi catchment of Kumaon hills in Uttarakhand showed that annual agricultural productivity declined by approximately 125 kg per ha (25%) during the last 30 years (1980–2010). This led to an annual food deficit of 1883 tonnes (65%), a large decline in per capita food production, as well as decreasing non-farm opportunities in the rural farm sector. The main reasons attributed to declining agricultural productivity included depleting natural resources and changing climatic conditions, amongst others (Tiwari and Joshi, 2012). The study further analyses that the amount of rainfall, as well as the number of rainy days, have declined by 52% and 34%, respectively, and the incidences of high-intensity rainfall and droughts have increased during 1995–2010 (Tiwari and Joshi, 2012). These changes heavily affect local livelihood systems, food security and water security in the region. One of the compounded effects of these impacts is outmigration.

There are future risks to agriculture from climate change. A Vulnerability and Risk Assessment (VRA) done by the SCCC of Uttarakhand has identified three specific impacts on how climate change could impact agriculture in the future (SCCC, n.d.). These include:

1. **Increased agricultural water stress**[52]: More extreme temperatures can increase evaporation and evapotranspiration losses which can cause water stress that would impact crop growth and yields, increase the susceptibility of crops to pests and diseases, and increase irrigation requirements. The districts of Almora, Champawat, Pauri Garhwal and Tehri Garhwal are likely to experience high water stress.
2. **Increased risk of floods**: The increased intensity of rainfall events can lead to flooding, causing crop losses, disruptions in transport and access to markets to sell agricultural goods.
3. **Changes in crop yields**: Changes in temperature and rainfall can affect crop water demand, productivity, and thereby yields (SCCC, n.d., p. 4). According to the VRA, a decrease in yields of wheat and paddy is likely in the hill districts of Uttarkashi, Chamoli, Rudraprayag and Pauri Garhwal under RCP4.5 (medium) and RCP8.5 (high) emissions scenarios.

Climate change impacts on agriculture are connected to outmigration. The factors above, which have decreased agricultural productivity, compounded by shrinking livelihood opportunities in traditional sectors, other ecological constraints, and poor infrastructure have contributed to outmigration from the hill districts of Uttarakhand (Hoermann et al., 2010; Jain, 2010; Joshi, 2018; Wester et al., 2019). Climate change and its links with agriculture, livelihoods, and consequences for migration can be understood as a feedback loop (see Figure 55).

[52] Agricultural water stress is defined as ratio of actual water uptake and potential transpiration.

Climate change impacts on water and agricultural productivity → impact livelihood and household income → people migrate → fewer people farm → more migration, abandoned fields and locked houses → ghost villages

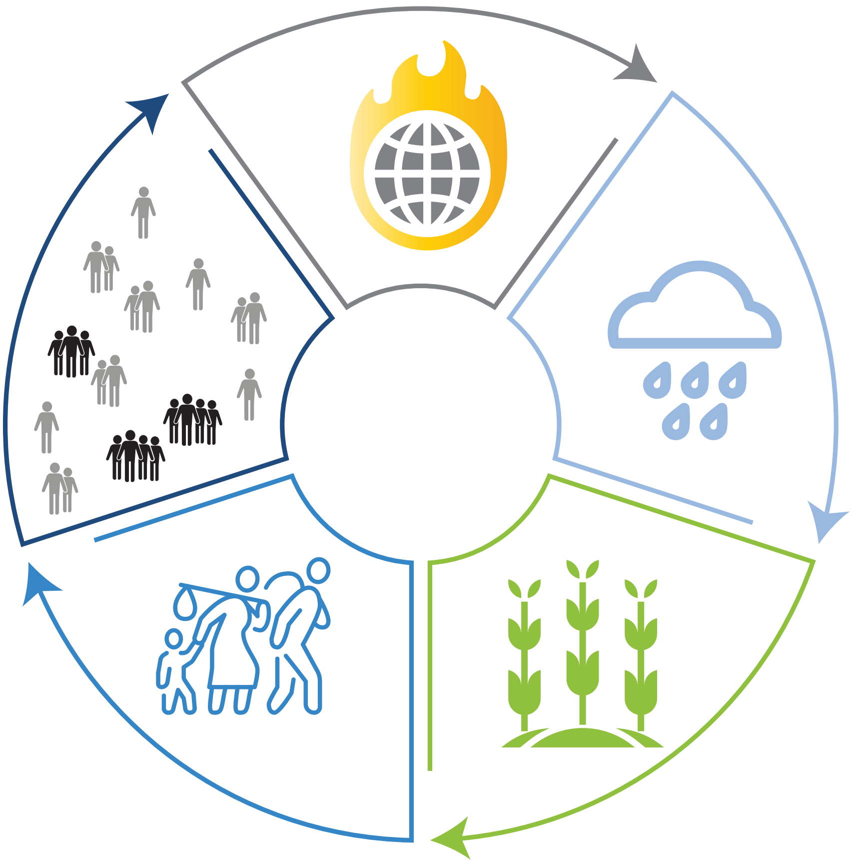


Figure 55: Climate change, agriculture and migration linkages in Uttarakhand

Communities are moving away from agriculture. In addition to the impacts of climate change and Uttarakhand's topographical limitations, there is also declining interest in practicing agriculture, especially amongst the youth. Traditionally, communities in hill districts have had subsistence-oriented, stable agriculture which combined crops, animal husbandry and forestry with resource recycling and collective sharing. However, this has changed. Economic growth, improved communications, better roads and digitalisation have led to rising aspirations for vastly different lifestyles. Satellite television has brought the outside world into people's daily lives. Similarly, mobile phones have helped foster previously unimaginable links and networks (Mehta, 2014). These changes have opened the door to opportunities in urban centres rather than the villages. The delinking of livelihoods from traditional land-based activities inevitably leads to the devaluation of such activities (Mehta, 2014). Young people, in particular, seek opportunities for a better life than those they see available in the village, resulting in outmigration. Though there has been a history of high rates of migration from hill regions, there was also a tendency for migrants to eventually return to their villages. This has now changed, with most migrants settling in their destination areas instead of returning (GU, 2018; Pathak et al., 2017).

However, not everyone can – or wants to – migrate. People unable or unwilling to move away from their place of origin despite facing climate impacts are rarely mentioned in the scientific literature on Uttarakhand. Scholars have categorized people who stay behind across a spectrum of 'immobility' (Black et al., 2013; Jónsson, 2011; Schewel, 2020; Zickgraf, 2019, 2018):

1. 'Trapped populations', who want to leave but are unable to migrate due to a lack of resources or because of family obligations, e.g., taking care of sick or elderly (Adams, 2016; Black et al., 2011; Foresight, 2011b).
2. People who want to remain rooted in place for socio-cultural belongingness (De Dominicis et al., 2015; Farbotko and McMichael, 2019; Mallick and Schanze, 2020)

Currently, studies on Uttarakhand focus mostly on outmigration and do not discuss those who stay behind (Bhandari and Reddy, 2015; Hoermann et al., 2010; Jain, 2010; Joshi, 2018; Mamgain and Reddy, 2016; Pathak et al., 2017; Tiwari and Joshi, 2016, 2015).

To conclude, in Uttarakhand, climate change is acting as risk modifier influencing existing population movements. Climate change impacts on agriculture are connected to outmigration in Uttarakhand. 70% of the population is dependent on rain-fed agriculture which is not highly productive. In the last two decades climate change has led to further decline in agricultural productivity, adding to outmigration. Observations show that low and uneven rainfall has led to a decrease in crop yields, while projections indicate an increase in agriculture water stress and further decrease in crop yields under RCP4.5 and RCP8.5. In many areas, mountain springs which provide the only source of water are drying due to climate change. This underscores the nexus between climate impacts, livelihood risks and migration. Figure 56 outlines the projected climate change, projected climate extremes, projected impacts on agriculture, current migration trends and population density. Hill districts in the north, west and central part of the state are more impacted and are likely to face higher risk to livelihoods as majority of the population is dependent on subsistence based rain-fed agriculture–adding to the existing outmigration from hill to plains districts.

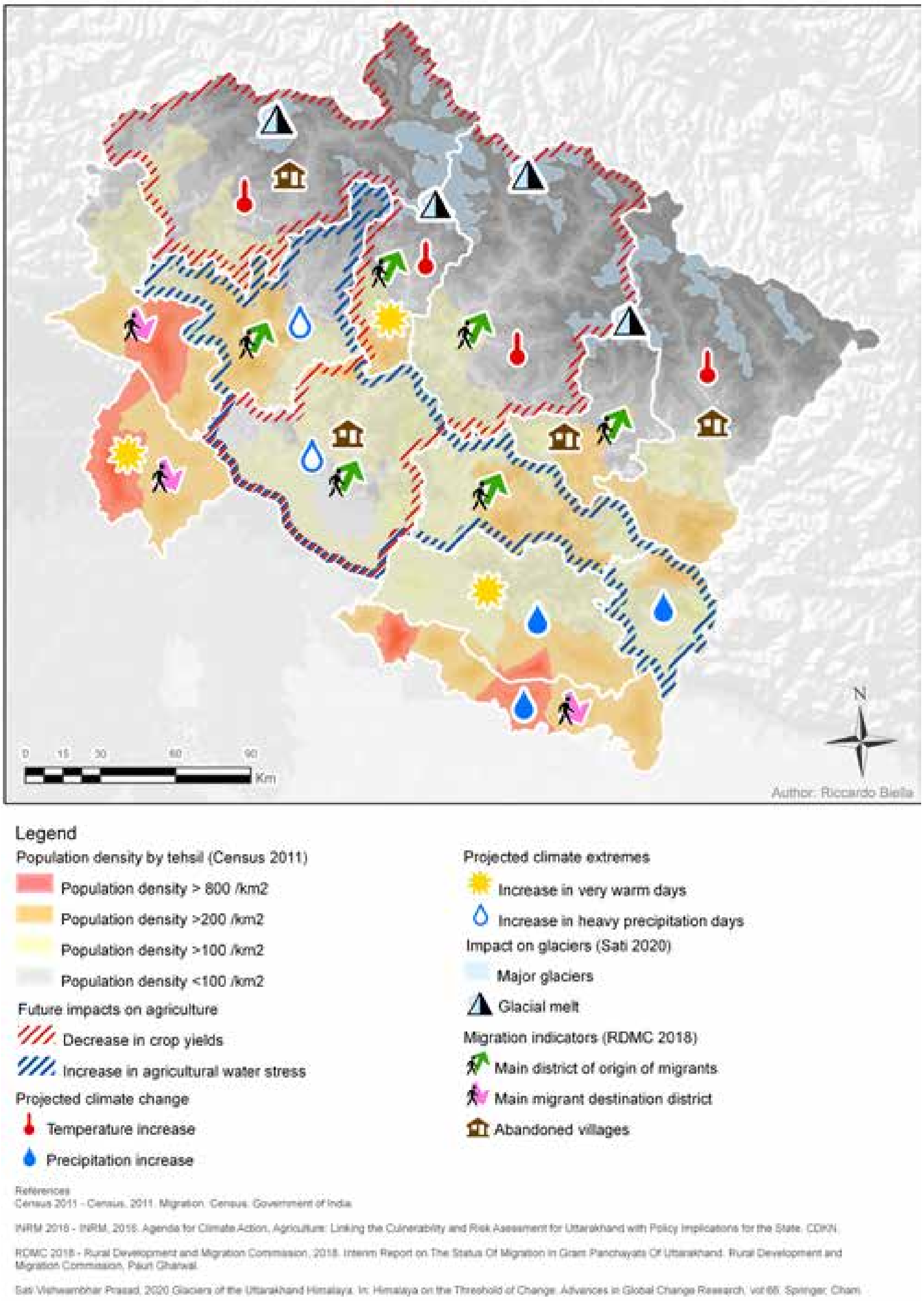


Figure 56: Livelihood risk map of Uttarakhand outlining projected climate change effects, projected climate extremes, impacts on agriculture, migration indicators and population density. Hill districts in the north, west and central part of the state are more affected and are likely to face higher livelihood risks as a majority of the population is dependent on subsistence-based, rain-fed agriculture – adding to the existing outmigration from hill to plains districts.

MIGRATION IN POLICIES AND PLANS

Snow covered Urgam village, Joshimat, Uttarakhand, India.

© Shutterstock/ Daniel Prudek

6 Migration in Policies and Plans

Migration is a cross-cutting issue of relevance to several policy fields. An analysis of the climate-migration nexus, therefore, requires an understanding of how different government policies and plans on climate change or sustainable development address migration interact, sometimes with contradictory effects. This section briefly discusses how the linkages between climate change, sustainable development and migration in Uttarakhand are tackled at the policy level.

Box 4: Uttarakhand Action Plan on Climate Change

(Government of Uttarakhand, 2014)

Prepared by the Government of Uttarakhand, the Uttarakhand Action Plan on Climate Change (UAPCC) lays out the ambitious plan of the Government to address climate change as it 'commits itself to fostering inclusive, sustainable and climate-resilient growth and development of the state' (p. 53). Building on a common implementation framework, the UAPCC discusses climate impacts on twelve sectors, agriculture among them, and formulates sectoral strategies for each. For instance, the plan presents migration as a strategy for livelihood diversification (p. 23), as a challenge for the state as continuing outmigration from rural areas leads to abandoned farm land (p. 36), and as a gender issue, with increased workloads for women as men outmigrate (p. 105). The plan identifies the climate-migration nexus as an understudied topic and proposes '[a] study on migration and its possible impacts (considering that there is significant migration within the state)' (p. 112). Several linkages between climate change, agriculture and migration dynamics from the hill districts are addressed:

- '[A] significant migration is taking place, especially from the hill districts – many farmers migrating to cities in search of better livelihood options, thereby leaving their land fallow and uncultivated' (p. 69)
- '[C]limate change-driven fluctuations in the precipitation pattern have increased uncertainty in the farm output' with the consequence that '[l]abour-intensive hill farming has thus been rendered unsustainable and the region is presently threatened by food insecurity' and, ultimately, '[t]he repercussions of this are clearly reflected in large stretches of hitherto regularly sown agricultural lands being left barren' (p. 115)
- As a result of male outmigration from hill districts to the plains '[t]he mountainous areas are thus left with women, the elderly and children', who belong to the most vulnerable sections of the society (p. 105)

Tourism, which is an important sector in the state, is briefly discussed as 'an excellent adaptation mechanism and an alternative livelihood option, with the potential to stem the large-scale migration from villages, if managed effectively' (p. 136).

Box 5: Report on Migration in Uttarakhand

Report on Status of Migration in Gram Panchayats of Uttarakhand
(Rural Development and Migration Commission, 2018)

In 2017, the Government of Uttarakhand set up the Rural Development and Migration Commission to address the issue of migration (Rural Development and Migration Commission, 2018, p. 2). The commission has several mandates, including the task 'to assess the quantum and extent of outmigration from different rural areas of the state' (p. 2). Based on this, the commission is supposed to develop ideas for rural development to 'promote welfare and prosperity of the rural population' and advise the government on development planning (p. 2). In 2018, the commission produced an interim report on migration based on extensive primary survey and secondary sources. According to the report, migration is a 'problem', 'challenge' and 'additional stressor' in the state due to:

- A dwindling primary sector (agriculture)
- Depopulation
- Crowding of cities
- Stressed resources due to inmigration

Furthermore, the commission's tasks also include to 'submit recommendations on vulnerable sections of the population of the state that are at risk of not adequately benefitting from economic progress' (p. 2).

Box 6: Uttarakhand Vision 2030

(Department of Planning, Government of Uttarakhand, 2018)

Based on the Sustainable Development Goals (SDGs) developed by the United Nations, the state of Uttarakhand developed the 'Uttarakhand: Vision 2030', which essentially functions as a road map for sustainable development in the state. The document sets out periodic targets for individual SDGs along with a strategy to implement them by 2030. The overall aim is to:

Transform the Uttarakhand economy into a prosperous, healthy state such that the people are educated and gainfully employed in an equitable society, synergy is enhanced between the environment and the inhabitants, and that the development process is sustainable and inclusive (p. 5).

Vision 2030 identifies migration from the hills to the plains as a challenge because it has increased the regional divide between hills and plains (p. 5). It also recognizes the dangers posed by state's vulnerable environment and points out that '[a]lthough the state does have a State Action Plan for Climate Change, there is little integration of climate change measures into state polices as yet' (p. 5). Uttarakhand's Department of Planning has identified ten focus areas for achieving its vision. While all ten have direct consequences for migration dynamics in the state, focus area 2, 'Reduce migration by transforming agriculture', and focus area 3, 'Reduce migration by providing livelihoods in hills', directly aim to at least slow rural outmigration from hill to plains districts.

Box 7: Sustainable Development in Indian Himalayan Region

Contributing to Sustainable Development in the Indian Himalayan Region
(Niti Aayog, Government of India, 2018)

At the federal level, the National Institute for Transforming India (NITI Aayog) has developed a plan of action for constituting five thematic focus areas aimed at bringing about sustainable development in the Indian Himalayan Region (IHR). The plan places migration among 'causes of concern': Deteriorating environmental assets, outmigration and the rapidly eroding cultural fabric and social value of collectivism unique to the IHR have become causes of concern' (p. 2). Climate change is said to further accentuate this situation (p. 2).

The plan aims to mitigate outmigration via its thematic group on 'Strengthening Skill and Entrepreneurship (E&S) Landscape in Indian Himalayan Region' which, inter alia, 'aims to identify potential unconventional areas for developing skills and entrepreneurship in IHR for scaling up to address issue of migration and unemployment' (p. 21).

WAY FORWARD IN RESEARCH AND POLICY

People seeking shelter from heavy rains in Dehradun, Uttarakhand, India.

© Shutterstock/ wintelineproductions.com

7 Way Forward in Research and Policy

The preceding sections elaborated on the current state of knowledge and evidence on linkages between climate change and migration in Uttarakhand. Based on this, the following section aims to conclude the report with highlighting some research gaps, data needs and policy recommendations for the government and its partners to understand better and plan for migration concerning climate change.

Research Gaps

More research is needed to understand the linkages between climate change impacts and migration in Uttarakhand. What are the contextual factors governing why some people migrate and why some stay under similar changing climatic conditions? Improved and enhanced understanding of such linkages can aid in adaptation planning and effectiveness. Some of the questions that could be pursued may include: Why does a state created for the hill people have the highest outmigration from the hill districts? Who is migrating, and who is staying back? What does the hills/plains divide tell us about resilience and vulnerabilities in the face of adverse consequences of climate change? What has changed the trend from the earlier single male outmigration to whole families migrating? Can people better afford the resources required for migration as compared to earlier? What happens to the abandoned fields, houses and villages turning into ghost villages?

More information is needed on understanding different types of mobilities under a changing climate. Mobility in Uttarakhand is discussed mainly under the umbrella of migration, mostly permanent and semi-permanent migration, while seasonal migration is rarely mentioned. Other forms of mobility, like transhumant pastoralism, are common in Uttarakhand (Dangwal, 2009; Mitra et al., 2013; Nautiyal et al., 2003). However, no studies explore how climate change might impact these traditional systems – which have socio-cultural, economic and ecological importance for pastoralist communities. Similarly, there are few studies on how climate change may affect the current cross-border farm labour migration from Nepal to Uttarakhand (Bruslé, 2008; Gill, 2003; Saxena et al., 2010). Likewise, there are no studies that examine displacement in Uttarakhand. There is no database on how many people got displaced in the 2013 flash floods in the state; what were the implications of such a displacement; and whether it led to permanent relocations or whether people returned (ADB, 2013; NIDM, 2014).

More research is needed on the implications of migration in Uttarakhand. What happens after people move? Available studies mostly discuss rural outmigration (Hoffmann et al., 2019; Joshi, 2018; Mamgain and Reddy, 2016; Rural Development and Migration Commission, 2018) and rarely extend to outcomes of such outmigration. However, it is critical to understand what happens in both sending and destination regions after migration. While studies document how climate change is impacting migration patterns (Jain, 2010; Maharjan et al., 2018; Tiwari and Joshi, 2015) they seldom look into the consequences of moving. Are people better adapted to the climate impacts in their destination areas or more vulnerable and exposed to new climate risks? In Uttarakhand, when people migrate, they often transition from farm-based to non-farm based labour. What are the implications of this for the state? Reports of uninhabited ghost villages, with locked houses and abandoned agricultural fields illustrate the situation in the hills (Dey, 2017; Upadhyay, 2018) but there is no scientific assessment on the effects of such outmigration. Further, there is no discussion about those who stay. Similarly, no studies are assessing the extensive in-migration of Nepalese farm labour.

More information is needed on populations who choose to stay or are unable to move. Research and assessment should be extended to those who stay behind, not just limited to those who migrate (Ayeb-Karlsson et al., 2018; Nawrotzki and DeWaard, 2018; Zickgraf, 2018). Some populations affected by environmental degradation and disasters may be unable to migrate, because of a lack of financial resources or difficulty accessing social networks. For example, women who stay back while men migrate (Mittal et al., 2008; Sekhar, 2007) are left the twin responsibility of managing both farm and household activities – while also coping with climate impacts. Although the most vulnerable strata of the society are able to migrate in certain situations, they have far fewer options than those with resources. Similarly more information is needed on those who voluntarily stay (Farbotko and McMichael, 2019; Mallick and Schanze, 2020)

More information is needed on the gender aspects of migration. Empirical evidence is needed on how migration decisions may be different for women and men. Is a woman's decision to migrate or not based on her household's needs and priorities, dependent on marital status, on education levels, on earning capacity in destination areas, or on individual desires? Do married women have less choice and are more likely to stay, while unmarried women have more choice and are more likely to migrate? In Uttarakhand women often stay behind while men migrate, though more women are migrating today. Collecting data on the characteristics of women who migrate and those who stay can shed light on these questions. When women migrate along with the household, the reason for migration is often given as 'migrated after marriage'. However, there is evidence across India that after migration women in destination regions become part of the labour force (Ministry of Housing and Urban Poverty Alleviation, 2017, pp. 5–7).

Research is needed on how rising temperatures can impact migration. There is scientific evidence that a future rise in temperature will be a risk to habitability (Xu et al., 2020), affect a population's ability to sustain their livelihoods (IOM, 2009), and impact health – especially those in manual occupations (Kjellstrom et al., 2016; Sahu et al., 2013) – and on how this can influence migration patterns (IOM, 2017; Mueller et al., 2014; Xu et al., 2020). Projected temperature increases in Uttarakhand could impact ecological resilience, local coping strategies and agrarian livelihoods and will surely affect migration. Heat stress is especially dangerous to migrant workers who do daily manual labour in outdoor environments (e.g., construction activities).

Data Needs

Comparable, longitudinal and georeferenced data are needed. Data is a challenge in climate change and migration research (IOM, 2009; Kaczan and Orgill-Meyer, 2020; Vinke, K.; Hoffmann, R., 2020). Migration data is often collected in the population census or migration census, but this not include information on how environmental degradation, climate change impacts or disasters affect it. These need to be explicitly asked about in questionnaires developed for data collection about migration. For example, in the Indian Census data, information on key drivers for migration are collected under 'employment', 'business', 'education', 'marriage' and 'others'. If someone migrated due to cyclone impacts or low harvest due to poor rains, etc., the design of the data collection will put these causes under 'others', masking the real reason for the movement. Also, the institutions and agencies responsible for data collection may not be trained on such topics. Therefore, such initiatives need to be complemented with the necessary training and capacity building. Data, particularly in terms of time series of environmental and demographic variables, is a major constraint for methodological innovation. Both temporal and spatial data at the finest resolutions are needed for producing better evidence. For example, long-term time series migration data for every agriculture season (when migration from agriculture-based households is likely to happen); data on who is moving; why they are moving; where they are moving to, etc. Efforts need to be made for collecting the finest resolution data, at the household or village level and not just at the higher levels of administration. Long-term longitudinal data that can be compared and geo-tagged could help assess migration trends and patterns and assist informed policymaking. For climate research, the lack of good-quality, historical meteorological data is often a limiting factor. The density and quality of meteorological stations in Uttarakhand need to be improved. More observations are critical to validate results from regional-scale models which can better represent regional conditions like the elevation patterns, orographic lifting, and other complex topographic features of Uttarakhand.

Data on household-level characteristics is must be collected. Migration decisions are often made at the household level (Stark and Bloom, 1985)[53]. However, the ability of individuals within households to migrate is differentiated by age, marital status, education, access to household material and financial resources, and decision-making capacity (Rao et al., 2020). All these factors can produce varying mobility outcomes for members of the same household. It is imperative to collect household-level data to understand migration at the household level. At the national level, the Census of India collects migration data only at administrative levels of governance (the national, state and district level). In contrast, at the state level, the Migration Commission (2017) has already made an encouraging step in collecting such data at the gram panchayat (village council) level. Further downscaling data collection to household level can facilitate a better understanding of migration patterns across different social characteristics. Such data could include different aspects of climate change vulnerability such as exposure and adaptive capacity to climate impacts.

Investments in statistical skills and capacities are needed. Coordination between different departments and agencies in data collection, following a standard protocol, could increase coherence and overall data accessibility. Currently, different methodologies at the national and state levels are used on heterogeneous spatial and temporal scales. For example, data on migration is collected by two main entities (i) the National Census which collects data every ten years up to the district level, and (ii) the National Sample Survey (NSS) which collects data without any fix periodicity but often up to the household level. They use different methodologies and definitions to collect data. This impedes comparison and cross-referencing across time periods. Furthermore, the migration data from the 2011 Census was released only in 2019, badly delaying time-sensitive analysis and research.

Innovative data sources to understand mobility patterns in the state should be considered. Mobile phone can be utilized to understand mobility trajectories (Boas, 2019). Such data has been used elsewhere to help understand a population's mobility behaviour, before and after disasters such as the earthquakes in Haiti (Bengtsson et al., 2011)

---

[53] Stark and Bloom (1985) developed the 'The New Economics of Labour Migration'. 'A key insight of this approach is that migration decisions are not made by isolated individual actors, but by larger units of related people – typically families or households – in which people act collectively not only to maximize expected income, but also to minimize risks and to loosen constraints associated with a variety of market failures, apart from those in the labour market' (in Massey et al., 1993, p. 436).

or cyclones in Bangladesh (Lu et al., 2016b, 2016a). According to the Socio-Economic and Caste Census of India, 2011, Uttarakhand had the third-most extensive mobile phone penetration in India, with 86.60% of households owning a mobile phone[54]. Analysing such data can illuminate the temporal and spatial characteristics of population movements. However, careful attention needs to be given to data security and other ethical considerations before analysing such data.

Recommendations for Policy

Developing an evidence base for climate change impacts and migration patterns in Uttarakhand. Migration is an effective household strategy to diversify the sources of income in the state. With a large majority (71%) of the population dependent on a climate-sensitive sector such as agriculture, changes in climatic parameters like temperature and rainfall are likely to make incomes volatile. This volatility gets accentuated by the limited alternate livelihood opportunities. As the Uttarakhand Action Plan on Climate Change notes 'the region does not have alternative gainful employment opportunities and climate change-driven uncertainly in mountain agriculture has forced people to migrate from the hills in search of employment' (GU, 2014, p. 105). Analysis from the Indian Himalayas shows that migration increases as environmental conditions reduce incomes (Banerjee, Gerlitz and Hoermann 2011).

Revisiting agricultural policies to address outmigration from hill districts. As discussed in Section 4.3, declining agricultural productivity is a reason for outmigration in the state. In their state-wide survey, Mamgain and Reddy found that 'farmers are willing to diversify their farm production to improve their income, but they need support' (Mamgain and Reddy 2016, p. 27). This could include introducing and training farmers on diversifying their crops. For example, growing cash crops like mushrooms that require less water. Or intercropping of medicinal and aromatic plants (MAPs)[55] with food grains. MAPs have a high return on investment and also have a high demand in the cosmetics and pharmaceutical sectors. They are also not eaten by wild animals (crop depredation by wild animals is a reason for outmigration, refer to Section 4.3). Farmers could also be provided with other support, such as better access to agriculture extension services, providing information on the process and full cycle of crop and animal insurance, development of irrigation channels and rainwater harvesting structures, provision of better quality seed, better access and connectivity to markets, or better marketing of horticulture crops such as apples. Redevelopment of abandoned lands could also generate new sources of income.

Introducing alternate livelihood options in the hill districts to revitalise the economy. In a survey conducted by the Migration Commission in 2017, a lack of employment opportunities emerged as the prime reason for outmigration (mentioned by approximately 50% of the respondents, for more see Section 4.3). Therefore, analysing the type and quality of employment opportunities available in the hills is the first step to understanding outmigration in the region. Second, as the percentage of working men is smaller in hill districts than working females, alternate

[54] https://secc.gov.in/stateSummaryReport#

[55] Uttarakhand State Action Plan on Climate Change notes 'there is huge commercial potential for the oils and essences extracted from MAPs. Aromatic plants such as lemon grass, citronella, palmarosa, chamomilla, tulsi, geranium, naramotha, Japanese mint, khus and marigold are used extensively in the cosmetic industry' (GU, 2014, pp. 72–73).

livelihood opportunities could target women. An excellent example of such an initiative is HILANS (Highland Innovative Livelihood Ascending Nature Sustainability)[56] which enables rural households to take up sustainable livelihood opportunities in the broader economy. This ongoing initiative targets women under its Livelihood Collective Programme and youth (around 60% of whom are women) under its Vocational Training Programme (ILSP, 2018). Women organise themselves to collect extra food grains, vegetables, fruits, etc. (those not used for household consumption) from households in their village and bring it to agro-processing centres set-up under this programme. They also work in these centres to produce baking products, pickles, jams and spreads, etc., which are then marketed and sold under the brand name of HILANS. This provides women with an alternate livelihood. Often these centres are near the village, so women can take care of their household responsibilities while being employed in such centres. Such programmes not only provide livelihoods but also skills training which opens up more employment opportunities. This program is already being implemented in eight hill districts in the state and could be replicated in other districts. In addition, other sectors could also be targeted, like tourism. Uttarakhand is blessed with natural assets, which could be harnessed for developing sustainable eco-parks. Home-stays in villages could be promoted, which could create employment for the local people. Climate is changing for the worse and keeping people in old jobs won't suffice, new business and employment opportunities need to be created. Systematic tourism could be one such option and could turn the historical economic disadvantage of the hills into an advantage.

Public institutions and government bodies need to prepare for demographic changes resulting from migration. Currently, the majority of people (70%) in Uttarakhand are migrating internally within the state, mostly from the hills to the plains and valleys. From a migration perspective, and in line with the principles of the Global Compact on Safe, Orderly and Regular Migration (GCM), to which India is a signatory, the responsible public institutions need to ensure safe and orderly migration of those on the move. From a climate adaptation perspective, research and policy need to focus on identification and prioritisation of strategies that can facilitate this, while also strengthening in situ adaptation options which allow people to adapt without leaving home. A twin-pronged approach is needed where proactive steps are taken to reduce the impact of climate change on communities while simultaneously planning for consequences of migration in the state. In the future, as discussed in Section 3, temperatures could rise from 1.6°C to 5.3 °C for different RCP scenarios. It could render some regions as inhabitable, especially in the plains. There could be a demographic turn, where people could migrate from plains to the hills. Though this needs further assessment and research. Nonetheless, public institutions need to assess, monitor and plan for such changes.

Preparing for adverse health impacts. In 2019, Uttarakhand had an unprecedented number of dengue cases. Health officials in the state attributed this to a changing climate (Mishra, 2019; Verma, 2019). An assessment of Uttarakhand shows that the temperature increase since 1990 has extended the window for malaria transmission in the state (Dhiman et al., 2019). Another study found new foci for malaria transmission in Uttarakhand for the future (the 2030s) under RCP4.5 (Sarkar et al. 2019, p. 9). Similarly, another study postulated that changing climatic conditions will make Uttarakhand more vulnerable to changes in the spatial and temporal distributions of vector-

[56] HILANS is a part of the Integrated Livelihood Support project (ILSP), a government body focused on improving rural economy through developing business enterprises (http://www.hilans.in/). To read more about ILPS, please refer here: https://ilsp.in/StaticData/Annual%20Report%202017-18%20ILSP.pdf.

borne diseases (VBDs) (Dhiman et al., 2010, p. 766). The combination of rising levels of vector-borne diseases with limited health care facilities could trigger more migration in the state.

Climate change policies and plans should recognize linkages between climate change and migration. The Uttarakhand Action Plan on Climate Change (2014) already identifies the need for a study to understand migration and its possible impacts (GU 2014, 112). The *Human Development Report of the State of Uttarakhand* emphasises the importance of managing migration in the state and summarises that 'the nature, causes, patterns and consequences of outmigration have changed over time' (GU, 2018); however, it makes no reference to climate change. A probable step in this direction could be to integrate climate change-migration linkages into existing vulnerability assessments (such as the vulnerability assessment done for the Indian Himalayan Region [DST 2019]), or the vulnerability assessment done at district and block level in Uttarakhand (INRM, 2016b). The studies commissioned by the government in the future on participatory rural appraisals could also incorporate questions on such linkages.

Mainstreaming migration into climate change policies and development policies. Though migration does not have a dedicated government department, with the Rural Development and Migration Commission in 2017, Uttarakhand is well-positioned to examine all aspects of migration in the state. The survey data collected at the gram panchayat (village council) level is a comprehensive dataset available on migration in the state. It provides a good foundation for conducting research and analysis and for improving the understanding of migration. Climate change could be integrated into this, by exploring when, how and why – in response to climate change impacts – people either chose to migrate or are unable to migrate. From a development policy perspective, geographically and culturally nuanced assessments at the ground level could be conducted. Such assessments can provide important information on how climate risks and migration outcomes differ, along with social characteristics like caste, gender, or age. This can help policymakers recognize the diversity of climate risks and mobilities, in different places and cultures, and inform decisions which will be politically and culturally acceptable.

A coherent approach at all levels of governance and public policy is needed. Climate change and migration is a dynamic and cross-sectoral subject for policymaking that demands an integrated approach. For instance, a working group on climate change and migration could be set up in the state with representation from diverse policy-making actors representing environmental, climate change, migration, rural development, urbanisation, agriculture, irrigation, water management and disaster management.

BIBLIOGRAPHY

Pine forest in Ranikhet, Uttarakhand.

8 Bibliography

Adams, H., 2016. Why populations persist: mobility, place attachment and climate change. Population and Environment 37, 429–448. https://doi.org/10.1007/s11111-015-0246-3

ADB, 2013. India: Uttarakhand Disaster 2013; Joint Rapid Damage and Needs Assessment Report. Asian Development Bank.

ADB, 2009. Climate Change and Migration in the Asia and Pacific. Asian Development Bank, Manila

Agarwal, A., Bhatnaga, N.K., Nema, R.K., Agrawal, N.K., 2012. Rainfall Dependence of Springs in the Midwestern Himalayan Hills of Uttarakhand. Mountain Research and Development 32, 446. https://doi.org/10.1659/MRD-JOURNAL-D-12-00054.1

Agarwal, B., 2010. Does Women's Proportional Strength Affect their Participation? Governing Local Forests in South Asia. World Development 38, 98–112. https://doi.org/10.1016/j.worlddev.2009.04.001

Awasthi, I.C., 2010. Migration Patterns in Hill Economy of Uttarakhand: Evidence from Field Enquiry. The Indian Economic Journal 57, 84–99. https://doi.org/10.1177/0019466220100406

Ayeb-Karlsson, S., Smith, C.D., Kniveton, D., 2018. A discursive review of the textual use of 'trapped' in environmental migration studies: The conceptual birth and troubled teenage years of trapped populations. Ambio 47, 557–573. https://doi.org/10.1007/s13280-017-1007-6

BAIF, 2011. Sustainable Rural Livelihood Creation and Natural Resource Management in Central and Western Himalayas. Bharatiya Agro Industries Foundation

Bandyopadhyay, J., Perveen, S., 2003. The Interlinking of Indian Rivers: Questions on the Scientific, Economic and Environmental Dimensions of the Proposal, in: Mirza, M.M.Q., Ahmed, A.U., Ahmad, Q.K. (Eds.), Interlinking Rivers in India: Issues and Concern. pp. 53–76

Banerjee, A., Dimri, A.P., Kumar, K., 2019. Rainfall over the Himalayan foot-hill region: Present and future. J Earth Syst Sci 129, 11. https://doi.org/10.1007/s12040-019-1295-2

Banerjee, S., Black, R., Mishra, A., Kniveton, D., 2018. Assessing vulnerability of remittance-recipient and nonrecipient households in rural communities affected by extreme weather events: Case studies from South-West China and North-East India. Population, Space and Place 1–15. https://doi.org/10.1002/psp.2157

Banerjee, S., Gerlitz, J.-Y., Hoermann, B., 2011. Labour migration as a response strategy to water hazards in the Hindu Kush-Himalayas. ICIMOD

Becker, C.M., Morrison, A.R., 1997. Beyond Urban Bias in Africa: Urbanization in an Era of Structural Adjustment. World Development 21, 535–554. https://doi.org/10.2307/221370

Bhandari, G., Reddy, B.V.C., 2015. Impact of Out-Migration on Agriculture and Women Work Load: An Economic Analysis of Hilly Regions of Uttarakhand, India. Indian Journal of Agricultural Economics 70, 10

Bhatt, I.D., Rawal, R.S., Dhar, U., 2000. The Availability, Fruit Yield, and Harvest of Myrica esculenta in Kumaun (West Himalaya), India. Mountain Research and Development 20, 146–153. https://doi.org/10.1659/0276-4741(2000)020[0146:TAFYAH]2.0.CO;2

Black, R., Adger, W.N., Arnell, N.W., Dercon, S., Geddes, A., Thomas, D., 2011. The effect of environmental change on human migration. Global Environmental Change 21, S3–S11. https://doi.org/10.1016/j.gloenvcha.2011.10.001

Black, R., Arnell, N.W., Adger, W.N., Thomas, D., Geddes, A., 2013. Migration, immobility and displacement outcomes following extreme events. Environmental Science & Policy 27, S32–S43. https://doi.org/10.1016/j.envsci.2012.09.001

Black, R., Kniveton, D., Skeldon, R., Coppard, D., Murata, A., Schmidt-Verkerk, K., 2008. Demographics and Climate Change: Future Trends And their Policy Implications for Migration. University of Sussex, Development Research Centre on Migration, Globalisation and Poverty

Boas, I., Farbotko, C., Adams, H., Sterly, H., Bush, S., van der Geest, K., Wiegel, H., Ashraf, H., Baldwin, A., Bettini, G., Blondin, S., de Bruijn, M., Durand-Delacre, D., Fröhlich, C., Gioli, G., Guaita, L., Hut, E., Jarawura, F.X., Lamers, M., Lietaer, S., Nash, S.L., Piguet, E., Rothe, D., Sakdapolrak, P., Smith, L., Tripathy Furlong, B., Turhan, E., Warner, J., Zickgraf, C., Black, R., Hulme, M., 2019. Climate migration myths. Nature Climate Change 9, 901–903. https://doi.org/10.1038/s41558-019-0633-3

Bond, T.C., Doherty, S.J., Fahey, D.W., Forster, P.M., Berntsen, T., DeAngelo, B.J., Flanner, M.G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P.K., Sarofim, M.C., Schultz, M.G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S.K., Hopke, P.K., Jacobson, M.Z., Kaiser, J.W., Klimont, Z., Lohmann, U., Schwarz, J.P., Shindell, D., Storelvmo, T., Warren, S.G., Zender, C.S., 2013. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres 118, 5380–5552. https://doi.org/10.1002/jgrd.50171

Boneva, B.S., Frieze, I.H., 2001. Toward a Concept of a Migrant Personality. J Social Issues 57, 477–491. https://doi.org/10.1111/0022-4537.00224

Bruslé, T., 2008. Choosing a Destination and Work: Migration Strategies of Nepalese Workers in Uttarakhand, Northern India. Mountain Research and Development 28, 240–247. https://doi.org/10.1659/mrd.0934

Buth, M., Kahlenborn, W., Greiving, S., Fleischhauer, M., Zebisch, M., Schneiderbauer, S., Schauser, I., 2017. Guidelines for Climate Impact and Vulnerability Assessments: Recommendations of the Interministerial Working Group on Adaptation to Climate Change of the German Federal Government. Umweltbundesamt, Dessau-Roßlau, Germany

Ca, R., Raju, B.M.K., Subbarao, A., kv, R., Rao, V., Ramachandran, K., Nagasri, K., Dupdal, R., Samuel, J., Shankar, K., Srinivasarao, M., Mandapaka, M., 2018. Climate change in Uttarakhand: Projections, Vulnerability and Farmers' Perceptions. Journal of Agrometeorology 20, 37–41

Census, 2011a. A-1 Number Of Villages, Towns, Households, Population And Area

Census, 2011b. Census of India 2011, Meta Data

Census, 2011c. Primary Census Abstract Data Tables (India & States/UTs - District Level) (Excel Format)

Census, 2011d. Migration. Census, Government of India

Census, 2011e. Implication of Terms Used in Indian Censuses

Chaturvedi, R.K., Joshi, J., Jayaraman, M., Bala, G., Ravindranath, N.H., 2012. Multi-model climate change projections for India under representative concentration pathways. CURRENT SCIENCE 103, 12

Chopra, R., 2014. Uttarakhand: Development and Ecological Sustainability

Chou, C., 2003. Land–sea heating contrast in an idealized Asian summer monsoon. Climate Dynamics 21, 11–25. https://doi.org/10.1007/s00382-003-0315-7

Dangwal, D.D., 2009. The Lost Mobility: Pastoralism and Modernity in Uttarakhand Himalaya (India). Nomadic Peoples 13, 84–101. https://doi.org/10.3167/np.2009.130206

Das, L., Meher, J.K., 2019. Drivers of climate over the Western Himalayan region of India: A review. Earth-Science Reviews 198, 102935. https://doi.org/10.1016/j.earscirev.2019.102935

Das, S., Ashrit, R., Moncrieff, M.W., 2006. Simulation of a Himalayan cloudburst event. Journal of Earth System Science 115, 299–313. https://doi.org/10.1007/BF02702044

De Dominicis, S., Fornara, F., Ganucci Cancellieri, U., Twigger-Ross, C., Bonaiuto, M., 2015. We are at risk, and so what? Place attachment, environmental risk perceptions and preventive coping behaviours. Journal of Environmental Psychology 43, 66–78. https://doi.org/10.1016/j.jenvp.2015.05.010

Department of Planning, GU, 2018. Uttarakhand Vision 2030

Deshingkar, P., Akter, S., 2009. Migration and Human Development in India. UNDP

Deshingkar, P., Farrington, J., 2009. Circular Migration and Multi-locational Livelihood Strategies in Rural India. Oxford University Press, New Delhi

Dey, A., 2017. Uttarakhand's ghost villages: Abandoned farms, empty homes and very few people. Scroll.in

Dhiman, R., Singh, Poonam, Yadav, Y., Saraswat, S., Kumar, G., Singh, R., Ojha, V., Joshi, B., Singh, Pankaj, 2019. Preparedness for malaria elimination in the wake of climate change in the State of Uttarakhand (India). J Vector Borne Dis 56, 46. https://doi.org/10.4103/0972-9062.257774

Dhiman, R.C., Pahwa, S., Dhillon, G.P.S., Dash, A.P., 2010. Climate change and threat of vector-borne diseases in India: are we prepared? Parasitol Res 106, 763–773. https://doi.org/10.1007/s00436-010-1767-4

Dhyani, P.P., 2015. State at a Glance: Uttarakhand. GBPIHED, Kosi-Katarmal, Almora

Dhyani, R.P., 1994. An approach to economic planning for the rural poor of central Himalayas. Classical Pub. Co., New Delhi

Dimri, A.P., Kumar, D., Choudhary, A., Maharana, P., 2018. Future changes over the Himalayas: Maximum and minimum temperature. Global and Planetary Change 162, 212–234. https://doi.org/10.1016/j.gloplacha.2018.01.015

DoRD, GoI, 2011. Socio- Economic and Caste Census

Douville, H., Royer, J.-F., Polcher, J., Cox, P., Gedney, N., Stephenson, D.B., Valdes, P.J., 2000. Impact of CO2 Doubling on the Asian Summer Monsoon: Robust Versus Model-dependent Responses. Journal of the Meteorological Society of Japan 78, 421–439. https://doi.org/10.2151/jmsj1965.78.4_421

DST, 2019a. Manual on Adaptation to Climate Change in the Indian Himalayan Region. Department of Science and Technology

DST, 2019b. Climate Vulnerability Assessment For The Indian Himalayan Region Using A Common Framework

Duan, K., Yao, T., Thompson, L.G., 2006. Response of monsoon precipitation in the Himalayas to global warming. Journal of Geophysical Research: Atmospheres 111. https://doi.org/10.1029/2006JD007084

Dugam, S., 2008. Role of North Atlantic oscillation and Southern oscillation in deficient and excess monsoon years. Indian Journal of Science and Technology 1. https://doi.org/10.17485/ijst/2008/v1i5/29350

Falco, C., Galeotti, M., Olper, A., 2019. Climate change and migration: Is agriculture the main channel? Global Environmental Change 59, 101995. https://doi.org/10.1016/j.gloenvcha.2019.101995

Farbotko, C., McMichael, C., 2019. Voluntary immobility and existential security in a changing climate in the Pacific. Asia Pac. Viewp. 60, 148–162. https://doi.org/10.1111/apv.12231

Field, C.B., Barros, V., Stocker, T.F., Dahe, Q. (Eds.), 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781139177245

Foresight, 2011a. Migration and Global Environmental Change. The Government Office for Science, London

Foresight, 2011b. Migration and Global Environmental Change (2011) Final Project Report. Government Office for Science, London

Forest Survey of India (FSI), 2019. India State of Forest Report 2019: Volume II. Forest Survey of India, Ministry of Environment, Forest & Climate Change, Government of India, Dehradun, India

Frieze, I.H., Hansen, S.B., Boneva, B., 2006. The migrant personality and college students' plans for geographic mobility. Journal of Environmental Psychology 26, 170–177. https://doi.org/10.1016/j.jenvp.2006.05.001

Gallaway, L.E., 1969. Age and Labor Mobility Patterns. Southern Economic Journal 36, 171. https://doi.org/10.2307/1056434

Gautam, Y., Andersen, P., 2016. Rural livelihood diversification and household well-being: Insights from Humla, Nepal. Journal of Rural Studies 44, 239–249. https://doi.org/10.1016/j.jrurstud.2016.02.001

Gill, G.J., 2003. Seasonal labour migration in rural Nepal: a preliminary overview. Overseas Development Institute, London

GIZ and EURAC, 2017. Risk Supplement to the Vulnerability Sourcebook. Guidance on how to apply the Vulnerability Sourcebook's approach with the new IPCC AR5 concept of climate risk. Bonn

Goswami, B.N., Kulkarni, J.R., Mujumdar, V.R., Chattopadhyay, R., 2010. On factors responsible for recent secular trend in the onset phase of monsoon intraseasonal oscillations. International Journal of Climatology 30, 2240–2246. https://doi.org/10.1002/joc.2041

Government of Himachal Pradesh, 2002. Himachal Pradesh Human Development Report. Planning Department

Government of Uttarakhand, 2019. State Profile [WWW Document]. Land Use. URL http://shm.uk.gov.in/pages/display/6-state-profile (accessed 1.21.20)

GU, 2018. Human Development Report of State of Uttarakhand. Department of Planning , Government of Uttarakhand

GU, 2014. Uttarakhand Action Plan on Climate Change: Transforming Crisis to Opportunity. Government of Uttarakhand

Habeeb, R., Javaid, S., 2019. Social Inclusion of Marginal in the Great Climate Change Debate: Case of Slums in Dehradun, India. SAGE Open 9, 215824401983592. https://doi.org/10.1177/2158244019835924

Hasnain, S.I., 2002. Himalayan glaciers meltdown: impact on. FRIEND 2002: Regional Hydrology: Bridging the Gap Between Research and Practice 417

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25, 1965–1978. https://doi.org/10.1002/joc.1276

Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, A., Molau, U., Morin, S., Orlove, B., Steltzer, H., 2019. High Mountain Areas. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. IPCC

Hoermann, B., Banerjee, S., Kollmair, M., 2010. Labour Migration for Development in the Western Hindu Kush-Himalayas. Understanding a livelihood strategy in the context of socioeconomic and environmental change. ICIMOD, Kathmandu

Hoffmann, E.M., Konerding, V., Nautiyal, S., Buerkert, A., 2019. Is the push-pull paradigm useful to explain rural-urban migration? A case study in Uttarakhand, India. PLoS ONE 14, e0214511. https://doi.org/10.1371/journal.pone.0214511

ILSP, 2018. Annual Report of ILSP 2017-18

INCCA, 2010. Climate Change and India: A 4x4 Assessment - A Sectoral and Regional Analysis for 2030s. Ministry of Environment & Forests, Government of India, Indian Government's Indian Network on Climate Change Assessment

INRM, 2016a. Uttarakhand Current and Future Climate Change Projections: Technical Report on Current Climate and Future Climate Change Projections (No. Technical Assistance-TAAS-0036). CDKN

INRM, 2016b. Climate Change Risks and Opportunities in Uttarakhand, India: Technical Report on District (Block) Level Vulnerability for Select Sectors (Deliverable#5 Draft Report). INRM Consultants Pvt Ltd, New Delhi

IOM, 2017. Extreme Heat and Migration, Extreme Heat and Migration: The Impacts Of Threats To Habitability From Increasing And Extreme Heat Exposure Due To Climate Change On Migration Movements

IOM, 2009. Migration, environment and climate change: assessing the evidence. International Organization for Migration, Geneva

IPCC, 2019. IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate

IPCC, 2014. Summary for Policymakers, in: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, pp. 1–32

IPCC, 2000. Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge; New York

IPCC, 1990a. Policymaker Summary of Working Group II (Potential Impacts of Climate Change). WMO, Geneva

IPCC, 1990b. Climate Change, The IPCC Impacts Assessment. Intergovernmental Panel on Climate Change

Isaac, R.K., Isaac, M., 2017. Vulnerability of Indian Agriculture to Climate Change: A Study of the Himalayan Region State 11, 7

Jacobson, C., Crevello, S., Chea, C., Jarihani, B., 2018. When is migration a maladaptive response to climate change? Regional Environmental Change. https://doi.org/10.1007/s10113-018-1387-6

Jain, A., 2010. Labour Migration and Remittances in Uttarakhand. ICIMOD

Jain, A., Nagarwalla, D.J., 2004. Why conserve forests? A baseline study to assess people's perceptions, attitudes and practices for increasing people's involvement in conservation. Appropriate Technology India, Dehradun

Jodha, N.S., 1992. Mountain perspective and sustainability: A framework for development strategy, in: Sustainable Mountain Agriculture. Oxford and IBH Co Pvt Ltd, New Delhi, India

Jónsson, G., 2011. Non-migrant, sedentary, immobile, or 'left behind'? 18

Joshi, B., 2018. Recent Trends of Rural Out-migration and its Socio-economic and Environmental Impacts in Uttarakhand Himalaya. Journal of Urban and Regional Studies on Contemporary India 4, 1–14

Kaczan, D.J., Orgill-Meyer, J., 2020. The impact of climate change on migration: a synthesis of recent empirical insights. Climatic Change 158, 281–300. https://doi.org/10.1007/s10584-019-02560-0

Kapos, V., Rhind, J., Edwards, M., Price, M.F., Ravilious, C., 2000. Developing a map of the world's mountain forests., in: Forests in Sustainable Mountain Development: A State of Knowledge Report for 2000. Task Force on Forests in Sustainable Mountain Development. CABI, Wallingford, pp. 4–19. https://doi.org/10.1079/9780851994468.0004

Kassie, G.W., Kim, S., Fellizar, F.P., Ho, B., 2017. Determinant factors of livelihood diversification: Evidence from Ethiopia. Cogent Social Sciences 3. https://doi.org/10.1080/23311886.2017.1369490

Kavi Kumar, K.S., Viswanathan, B., 2013. Influence of weather on temporary and permanent migration and in rural India. Climate Change Economics 04, 1350007. https://doi.org/10.1142/S2010007813500073

Kelkar, U., Narula, K.K., Sharma, V.P., Chandna, U., 2008a. Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. Global Environmental Change 18, 564–574. https://doi.org/10.1016/j.gloenvcha.2008.09.003

Kelkar, U., Narula, K.K., Sharma, V.P., Chandna, U., 2008b. Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. Global Environmental Change 18, 564–574. https://doi.org/10.1016/j.gloenvcha.2008.09.003

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O., 2016. Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. Annu. Rev. Public Health 37, 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740

Kniveton, D., Schmidt-Verkerk, K., Smith, C., Black, R., 2008. Climate Change and Migration: Improving Methodologies to Estimate Flows, IOM Migration Research Series. UN. https://doi.org/10.18356/6233a4b6-en

Knutson, T.R., Delworth, T.L., Dixon, K.W., Held, I.M., Lu, J., Ramaswamy, V., Schwarzkopf, M.D., Stenchikov, G., Stouffer, R.J., 2006. Assessment of Twentieth-Century Regional Surface Temperature Trends Using the GFDL CM2 Coupled Models. J. Climate 19, 1624–1651. https://doi.org/10.1175/JCLI3709.1

Kohler, T., Maselli, D., Universität Bern (Eds.), 2009. Mountains and climate change: from understanding to action. CDE, Bern

Krishnan, R., Shrestha, A.B., Ren, G., Rajbhandari, R., Saeed, S., Sanjay, J., Syed, Md.A., Vellore, R., Xu, Y., You, Q., Ren, Y., 2019. Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes, in: Wester, P., Mishra, A., Mukherji, A., Shrestha, Arun Bhakta (Eds.), The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer International Publishing, Cham, pp. 57–97. https://doi.org/10.1007/978-3-319-92288-1_3

Kumar, A., 2011. The Making of a Small State: Populist Social Mobilisation and the Hindi Press in the Uttarakhand Movement. Orient Blackswan, New Delhi

Kumar, A., Gupta, A.K., Bhambri, R., Verma, A., Tiwari, S.K., Asthana, A.K.L., 2018. Assessment and review of hydrometeorological aspects for cloudburst and flash flood events in the third pole region (Indian Himalaya). Polar Science 18, 5–20. https://doi.org/10.1016/j.polar.2018.08.004

Kumar, K., Satyal, G.S., Kandpal, K.D., 2006. Farmer and state managed hill irrigation systems in Kumaun Himalayas 5, 7

Kumar, N., Jaswal, A.K., 2016. Historical temporal variation in precipitation over Western Himalayan Region: 1857-2006. J. Mt. Sci. 13, 672–681. https://doi.org/10.1007/s11629-014-3194-y

Kuniyal, J.C., 2002. Mountain expeditions: minimising the impact. Environmental Impact Assessment Review 6, 561–581

Linkenbach, A., 2002. Shaking the State by Making a (New) State? Fighting for Autonomy in the Central Himalaya (North India). Sociologus 52, 77–106

Macchi, M., 2011. Framework for Community-Based Climate Vulnerability and Capacity Assessment in Mountain Areas. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal

Macchi, M., Gurung, A.M., Hoermann, B., 2015. Community perceptions and responses to climate variability and change in the Himalayas. Climate and Development 7, 414–425. https://doi.org/10.1080/17565529.2014.966046

Mach, K.J., Planton, S., von Stechow, C., 2014. Annex II: Glossary, in: Pachauri, R.K., Meyer, L. (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, pp. 117–130

Maharjan, A., Hussain, A., Bhadwal, S., Ishaq, S., Saeed, B.A., Sachdeva, I., Ahmad, B., Hassan, S.M.T., Tuladha, S., Ferdous, J., 2018. Migration in the Lives of Environmentally Vulnerable Populations in Four River Basins of the Hindu Kush Himalayan Region (No. HI-AWARE Working Paper 20)

Maikhuri, R., 2012. Climate change adaptation and mitigation: Insights from Nanda Devi Biosphere Reserve in Indian Himalaya

Maikhuri, R.K., Rao, K.S., Semwal, R.L., 2001. Changing scenario of Himalayan agroecosystems: loss of agrobiodiversity, an indicator of environmental change in Central Himalaya, India. The Environmentalist 21, 23–39. https://doi.org/10.1023/A:1010638104135

Maikhuri, R.K., Rawat, L.S., Nautiyal, S., Negi, V.S., Pharswan, D.S., Phondani, P., 2013. Promoting and enhancing sustainable livelihood options as an adaptive strategy to reduce vulnerability and increase resilience to climate change impact in the Central Himalaya, in: Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change. Springer, pp. 555–574

Maikhuri, R.K., Semwal, R.L., Rao, K.S., Nautiyal, S., Saxena, K.G., 1997. Eroding traditional crop diversity imperils the sustainability of agricultural systems in Central Himalaya. Current Science Association 73, 777–782

Maithani, P., 1996. Towards Sustinable Hill Area Development:Himalaya. Man and Nature 16, 4–7

Mallick, B., Schanze, J., 2020. Trapped or Voluntary? Non-Migration Despite Climate Risks. Sustainability 12, 4718. https://doi.org/10.3390/su12114718

Mamgain, R., Reddy, D.N., 2016. Outmigration from the hills of Uttarakhand: Magnitude, Challenges and Policy Options. Giri Institute of Development Studies

Mamgain, R.P., 2004. Employment, migration and livelihoods in the hill economy of Uttaranchal

Mamgain, R.P., Suryanarayana, M.H., 2017. Estimation of District Level Poverty In Uttarakhand

Massey, D.S., Arango, J., Hugo, G., Kouaouci, A., Pellegrino, A., Taylor, J.E., 1993. Theories of International Migration: A Review and Appraisal. Population and Development Review 19, 431. https://doi.org/10.2307/2938462

Maurer, J.M., Schaefer, J.M., Rupper, S., Corley, A., 2019. Acceleration of ice loss across the Himalayas over the past 40 years. Sci. Adv. 5, eaav7266. https://doi.org/10.1126/sciadv.aav7266

McLeman, R., Smit, B., 2006. Migration as an Adaptation to Climate Change. Climatic Change 76, 31–53. https://doi.org/10.1007/s10584-005-9000-7

McLeman, R.A., Hunter, L.M., 2010. Migration in the context of vulnerability and adaptation to climate change: insights from analogues: Migration and adaptation to climate change. Wiley Interdisciplinary Reviews: Climate Change 1, 450–461. https://doi.org/10.1002/wcc.51

Meher, J.K., Das, L., Akhter, J., Benestad, R.E., Mezghani, A., 2017. Performance of CMIP3 and CMIP5 GCMs to Simulate Observed Rainfall Characteristics over the Western Himalayan Region. J. Climate 30, 7777–7799. https://doi.org/10.1175/JCLI-D-16-0774.1

Meher, J.K., Das, L., Benestad, R.E., Mezghani, A., 2018. Analysis of winter rainfall change statistics over the Western Himalaya: the influence of internal variability and topography. International Journal of Climatology 38, e475–e496. https://doi.org/10.1002/joc.5385

Mehta, M., 2014. Neither of the hills nor of the city: Glimpses of peri-urban lives in a time of rapid change. Doon Library and Research Centre

Menon, S., Hansen, J., Nazarenko, L., Luo, Y., 2002. Climate effects of black carbon aerosols in China and India. Science (New York, N.Y.) 297, 2250–2253. https://doi.org/10.1126/science.1075159

Ministry of Housing and Urban Poverty Alleviation, 2017. Report of the the Working Group of Migration

Mishra, A., 2017. Changing Temperature and Rainfall Patterns of Uttarakhand. IJESNR 7. https://doi.org/10.19080/IJESNR.2017.07.555716

Mishra, A., 2014. Changing Climate of Uttarakhand, India. J Geol Geosci 03. https://doi.org/10.4172/2329-6755.1000163

Mishra, I., 2019. Despite mercury dip, dengue cases continue to rise in Uttarakhand. Times of India

Mishra, N.B., Chaudhuri, G., 2015. Spatio-temporal analysis of trends in seasonal vegetation productivity across Uttarakhand, Indian Himalayas, 2000–2014. Applied Geography 56, 29–41. https://doi.org/10.1016/j.apgeog.2014.10.007

Mitra, M., Kumar, A., Adhikari, B.S., Rawat, G.S., 2013. A note on transhumant pastoralism in Niti valley, Western Himalaya, India. Pastor Res Policy Pract 3, 29. https://doi.org/10.1186/2041-7136-3-29

Mittal, S., Tripathi, G., Sethi, D., 2008. Development Strategy for the Hill Districts of Uttarakhand (No. Working Paper 217). Indian Council for Research on International Economic Relations

MOSPI, 2007. Agriculture and Allied Activities (National Accounts Statistics-Sources & Methods). Ministry of Statistics and Programme Implementation

Mueller, V., Gray, C., Kosec, K., 2014. Heat stress increases long-term human migration in rural Pakistan. Nature Clim Change 4, 182–185. https://doi.org/10.1038/nclimate2103

Nandargi, S., Gaur, A., Mulye, S.S., 2016. Hydrological analysis of extreme rainfall events and severe rainstorms over Uttarakhand, India. Hydrological Sciences Journal 61, 2145–2163. https://doi.org/10.1080/02626667.2015.1085990

Naudiyal, N., Arunachalam, K., Kumar, U., 2019. The future of mountain agriculture amidst continual farm-exit, livelihood diversification and outmigration in the Central Himalayan villages. J. Mt. Sci. 16, 755–768. https://doi.org/10.1007/s11629-018-5160-6

Nautiyal, S., Rao, K.S., Maikhuri, R.K., Saxena, K.G., 2003. Transhumant Pastoralism in the Nanda Devi Biosphere Reserve, India: A Case Study in the Buffer Zone. Mountain Research and Development 23, 255–262. https://doi.org/10.1659/0276-4741(2003)023[0255:TPITND]2.0.CO;2

Nawrotzki, R.J., DeWaard, J., 2018. Putting trapped populations into place: climate change and inter-district migration flows in Zambia. Reg Environ Change 18, 533–546. https://doi.org/10.1007/s10113-017-1224-3

Negi, G.C.S., Samal, P.K., Kuniyal, J.C., Kothyari, B.P., Sharma, R.K., Dhyani, P.P., 2012. Impact of climate change on the western Himalayan mountain ecosystems: An overview 53, 345–356

NIDM, 2014. India Disaster Report 2013. National Institute of Disaster Management

Palazzi, E., von Hardenberg, J., Terzago, S., Provenzale, A., 2015. Precipitation in the Karakoram-Himalaya: a CMIP5 view. Clim Dyn 45, 21–45. https://doi.org/10.1007/s00382-014-2341-z

Pandey, V.K., Mishra, A., 2015. Causes and Disaster Risk Reduction Measures for Hydrometerological Disaster in Uttarakhand, India: An Overview 20

Pathak, S., 1999. Beyond An Autonomous State Background and Preliminary Analysis of Uttarakhand Movement. Proceedings of the Indian History Congress 60, 893–907

Pathak, S., Pant, L., Maharjan, A., 2017. De-population trends, patterns and effects in Uttarakhand, India – A gateway to Kailash Mansarovar. ICIMOD, Kathmandu

Pepin, N., Bradley, R.S., Diaz, H.F., Baraer, M., Caceres, E.B., Forsythe, N., Fowler, H., Greenwood, G., Hashmi, M.Z., Liu, X.D., Miller, J.R., Ning, L., Ohmura, A., Palazzi, E., Rangwala, I., Schöner, W., Severskiy, I., Shahgedanova, M., Wang, M.B., Williamson, S.N., Yang, D.Q., Mountain Research Initiative EDW Working Group, 2015. Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5, 424–430. https://doi.org/10.1038/nclimate2563

Piguet, E., 2010. Linking climate change, environmental degradation, and migration: a methodological overview. WIREs Climate Change 1, 517–524. https://doi.org/10.1002/wcc.54

Planning Commission, GoI, 2013. Press Notes on Poverty Estimates 2011-2012. Government of India

Planning Commission, GoI, 2007. Press Notes on Poverty Estimates 2004-2005. Government of India, New Delhi

Planning Commission, GU, 2017. Uttarakhand State Economic Survey 2016-17

Pranuthi, G., Dubey, S.K., Tripathi, S.K., Chandniha, S.K., 2014. Trend and Change Point Detection of Precipitation in Urbanizing Districts of Uttarakhand in India. Indian Journal of Science and Technology 7, 10

Press Trust of India, 2018. Deserted houses, wild fields: Where have people gone from Uttarakhand's 734 villages? Hindustan Times

Pritchard, H.D., 2019. Asia's shrinking glaciers protect large populations from drought stress. Nature 569, 649–654. https://doi.org/10.1038/s41586-019-1240-1

Rama Rao, C.A., Raju, B.M.K., Subba Rao, A.V.M., Rao, K.V., Rao, V.U.M., Ramachandran, K., Venkateswarlu, B., Sikka, A.K., 2013. Atlas on Vulnerability of Indian Agriculture to Climate Change. Central Research Institute for Dryland Agriculture, Hyderabad

Ramachandraiah, C., 1995. Revenue Village vs Real Village: Under-Enumeration and Non-Enumeration under Srisailam Project 30, 2301–2302

Ramanathan, V., Chung, C., Kim, D., Bettge, T., Buja, L., Kiehl, J.T., Washington, W.M., Fu, Q., Sikka, D.R., Wild, M., 2005. Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle. Proceedings of the National Academy of Sciences 102, 5326–5333. https://doi.org/10.1073/pnas.0500656102

Rao, N., Singh, C., Solomon, D., Camfield, L., Sidiki, R., Angula, M., Poonacha, P., Sidibé, A., Lawson, E.T., 2020. Managing risk, changing aspirations and household dynamics: Implications for wellbeing and adaptation in semi-arid Africa and India. World Development 125, 104667. https://doi.org/10.1016/j.worlddev.2019.104667

Rasul, G., Saboor, A., Tiwari, P.C., Hussain, A., Ghosh, N., Chettri, G.B., 2019. Food and Nutrition Security in the Hindu Kush Himalaya: Unique Challenges and Niche Opportunities, in: Wester, P., Mishra, A., Mukherji, A., Shrestha, A.B. (Eds.), The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer International Publishing, Cham, pp. 301–338. https://doi.org/10.1007/978-3-319-92288-1_9

Rautela, P., Karki, B., 2015. Traditional Practices for Survival in Resource Depleted Himalayan Region: Challenges Put Forth by Climate Change and Response of Local Communities 4, 11

Ravera, F., Martín-López, B., Pascual, U., Drucker, A., 2016. The diversity of gendered adaptation strategies to climate change of Indian farmers: A feminist intersectional approach. Ambio 45, 335–351

Rigaud, K.K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McCusker, B., Heuser, S., Midgley, A., 2018. Groundswell: Preparing for Internal Climate Migration. World Bank. https://doi.org/10.1596/29461

Rural Development and Migration Commission, 2018. Interim Report on the Status of Migration in Gram Panchayats of Uttarakhand. Rural Development and Migration Commission, Pauri Gharwal

Sahu, S., Sett, M., Kjellstrom, T., 2013. Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India: Implications for a Climate Change Future. Ind Health 51, 424–431. https://doi.org/10.2486/indhealth.2013-0006

Sarkar, S., Gangare, V., Singh, P., Dhiman, R.C., 2019. Shift in Potential Malaria Transmission Areas in India, Using the Fuzzy-Based Climate Suitability Malaria Transmission (FCSMT) Model under Changing Climatic Conditions. IJERPH 16, 3474. https://doi.org/10.3390/ijerph16183474

Sati, V.P., 2020. Himalaya on the Threshold of Change, Advances in Global Change Research. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-14180-6

Sati, V.P., 2016. Patterns and Implications of Rural-Urban Migration in the Uttarakhand Himalaya, India. Annals of Natural Sciences 2, 26–37

Saxena, K.G., Rao, K.S., Nautiyal, S., 2010. Assessment Report Nanda Devi Biosphere Reserve, Uttarakhand, India as a baseline for further studies related to the implementation of Global Change in Mountain Regions (GLOCHAMORE) Research Strategy (No. Contract No. 3240206475). UNESCO India

SCCC, n.d. Agenda for Climate Action: Agriculture Linking the Vulnerability and Risk Assesment for Uttarakahnd with policy implications for the state. State Climate Change Centre, Uttarakhand Forest Department, Government of Uttarakhand

Schewel, K., 2020. Understanding Immobility: Moving Beyond the Mobility Bias in Migration Studies. International Migration Review 54, 328–355. https://doi.org/10.1177/0197918319831952

Schwartz, A., 1973. Interpreting the Effect of Distance on Migration. Journal of Political Economy 81, 1153–1169. https://doi.org/10.1086/260111

Sekhar, C.S.C., 2007. Viable Entrepreneurial Trade For Women In Agriculture In Uttaranchal. University of Delhi

Semwal, R., Nautiyal, S., Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S., Saxena, K.G., 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agriculture, Ecosystems & Environment 102, 81–92

Sherpa, D., 2007. New Vulnerabilities for Mountain Women: A Different Light on the Greater Himalaya

Shukla, R., Agarwal, A., Gornott, C., Sachdeva, K., Joshi, P.K., 2019. Farmer typology to understand differentiated climate change adaptation in Himalaya. Sci Rep 9, 1–12. https://doi.org/10.1038/s41598-019-56931-9

Shukla, R., Chakraborty, A., Sachdeva, K., Joshi, P.K., 2018. Agriculture in the western Himalayas – an asset turning into a liability. Development in Practice 28, 318–324. https://doi.org/10.1080/09614524.2018.1420140

SIDCUL, 2015. State Infrastructure & Industrial Development Corporation Uttarakhand Ltd [WWW Document]. URL https://www.siidcul.com/about/siidcul

Sperber, K.R., Annamalai, H., Kang, I.-S., Kitoh, A., Moise, A., Turner, A., Wang, B., Zhou, T., 2013. The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. Clim Dyn 41, 2711–2744. https://doi.org/10.1007/s00382-012-1607-6

Stark, O., Bloom, D.E., 1985. The New Economics of Labor Migration. The American Economic Review, Papers and Proceedings of theNinety-Seventh Annual Meeting of the American Economic Association 75, 173–178

State Climate Change Centre, n.d. Agenda for Climate Action: Agriculture Linking the Vulnerability and Risk Assessment for Uttarakhand with policy implications for the state. Uttarakhand Forest Department, Government of Uttarakhand

Sunderesan, J., Gupta, P., Santosh, K., Boojh, R. (Eds.), 2014. Climate Change and Himalaya: Natural Hazards and Mountain Resources. Scientific Publishers

Sutton, R.T., Dong, B., Gregory, J.M., 2007. Land/sea warming ratio in response to climate change: IPCC AR4 model results and comparison with observations. Geophysical Research Letters 34. https://doi.org/10.1029/2006GL028164

Tambe, S., Kharel, G., Arrawatia, M.L., Kulkarni, H., Mahamuni, K., Ganeriwala, A.K., 2012. Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. Mountain Research and Development 32, 62–72

Tewari, V.P., Verma, R.K., von Gadow, K., 2017. Climate change effects in the Western Himalayan ecosystems of India: evidence and strategies. Forest Ecosystems 4, 13. https://doi.org/10.1186/s40663-017-0100-4

Tiwari, P.C., Joshi, B., 2016. Gender processes in rural outmigration and socio-economic development in the Himalaya. Migration and Development 5, 330–350. https://doi.org/10.1080/21632324.2015.1022970

Tiwari, P.C., Joshi, B., 2015. Climate Change and Rural Out-migration in Himalaya. Change and Adaptation in Socio-Ecological Systems 2. https://doi.org/10.1515/cass-2015-0002

Tiwari, P.C., Joshi, B., 2012. Natural and socio-economic factors affecting food security in the Himalayas. Food Sec. 4, 195–207. https://doi.org/10.1007/s12571-012-0178-z

Trenberth, K.E., 2008. The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts. In Encyclopedia of Hydrological Sciences. https://doi.org/10.1002/0470848944.hsa211

Turner, A.G., Annamalai, H., 2012. Climate change and the South Asian summer monsoon. Nature Climate Change 2, 587–595. https://doi.org/10.1038/nclimate1495

Ueda, H., Iwai, A., Kuwako, K., Hori, M.E., 2006. Impact of anthropogenic forcing on the Asian summer monsoon as simulated by eight GCMs. Geophysical Research Letters 33. https://doi.org/10.1029/2005GL025336

United Nations, 2018. General Assembly Resolution 73/195, Global Compact for Safe, Orderly and Regular Migration A/RES/73/195 (19 December 2018)

United Nations Development Programme (UNDP), 2019. Human development report 2019: beyond income, beyond averages, beyond today: inequalities in human development in the 21st century. New York, USA

United Nations Development Programme (UNDP), 2018. Human Development Indices and Indicators: 2018 Statistical Update. New York, USA

United Nations Development Programme (UNDP), n.d. Gender Development Index (GDI) | Human Development Reports [WWW Document]. URL http://hdr.undp.org/en/content/gender-development-index-gdi (accessed 7.9.20)

Upadhyay, K., 2018. Inside the ghost villages of Uttarakhand. Indian Express

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K., 2011. The representative concentration pathways: an overview. Climatic Change 109, 5. https://doi.org/10.1007/s10584-011-0148-z

Venkatesh, S., 2016. Why this abandoned village is a threat to Uttarakhand. Down to Earth

Verma, L., 2019. Uttarakhand: Spike in dengue cases, officials cite climate. Indian Express

Vinke, K.; Hoffmann, R., 2020. Data for a difficult subject: Climate change and human migration. Migration Policy Practice X, 16–22

Viviroli, D., Dürr, H.H., Messerli, B., Meybeck, M., Weingartner, R., 2007. Mountains of the world, water towers for humanity: Typology, mapping, and global significance: MOUNTAINS AS WATER TOWERS FOR HUMANITY. Water Resour. Res. 43. https://doi.org/10.1029/2006WR005653

Viviroli, D., Weingartner, R., Messerli, B., 2003. Assessing the Hydrological Significance of the World's Mountains. Mountain Research and Development 23, 32–40. https://doi.org/10.1659/0276-4741(2003)023[0032:ATHSOT]2.0.CO;2

Wang, B., Ding, Q., Joseph, P.V., 2009. Objective Definition of the Indian Summer Monsoon Onset. J. Climate 22, 3303–3316. https://doi.org/10.1175/2008JCLI2675.1

Warner, K., Hamza, M., Oliver-Smith, A., Renaud, F., Julca, A., 2010. Climate change, environmental degradation and migration. Nat Hazards 55, 689–715. https://doi.org/10.1007/s11069-009-9419-7

Wester, P., Mishra, A., Mukherji, A., Shrestha, A.B., 2019. The Hindu Kush Himalaya assessment: mountains, climate change, sustainability and people

White, G., 2011. Climate-Induced Migration: An Essentially Contested Concept, in: Climate Change and Migration. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199794829.003.0001

Wise, W., Covarrubias, H.M., 2009. Understanding the Relationship between Migration and Development: Toward a New Theoretical Approach. Social Analysis 53, 530305. https://doi.org/10.3167/sa.2009.530305

Xiao, C.-D., Wang, S.-J., Qin, D.-H., 2015. A preliminary study of cryosphere service function and value evaluation. Advances in Climate Change Research 6, 181–187. https://doi.org/10.1016/j.accre.2015.11.004

Xu, C., Kohler, T.A., Lenton, T.M., Svenning, J.-C., Scheffer, M., 2020. Future of the human climate niche. Proc Natl Acad Sci USA 117, 11350–11355. https://doi.org/10.1073/pnas.1910114117

Yadav, R., Tripathi, S.K., Pranuthi, G., Dubey, S.K., 2014. Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand 16, 9

Zickgraf, 2019. Keeping People in Place: Political Factors of (Im)mobility and Climate Change. Social Sciences 8, 228. https://doi.org/10.3390/socsci8080228

Zickgraf, C., 2018. Immobility, in: Gemenne, F., McLeman, R. (Eds.), Routledge Handbook on Environmental Displacement and Migration. Routledge

APPENDIX

Rishikesh, yoga city India, Gange River valley, Ganga, Uttarakhand during sunset.

9 Appendix

Box 8: Uttarakhand Movement

Uttarakhand Movement: a demand for a separate state

Nearly fifty years after the demand for a separate state for those living in the hills had first been formally articulated by P.C. Joshi, then General Secretary of the Communist Party of India (Linkenbach, 2002), Uttarakhand became the 27th state of India. The territory of the new state was carved out from northern and hilly parts of its parent state Uttar Pradesh. The formation of the state on 9 November 2000 was the outcome of a long and persistent demand from the people of what is now Uttarakhand, who felt that the interests and concerns of those living in the hills were underrepresented in the political process of Uttar Pradesh. They stood united in the face of challenges such as economic backwardness or the lack of a clear political identity (Government of Uttarakhand, 2014; Rural Development and Migration Commission, 2018). While P.C. Joshi had already proposed a separate hill state in 1952, the movement only gained momentum in 1994 and transformed into a Jan Andolan (people's movement). It was an autonomous people's movement which functioned without any central leadership and came to be known as the Uttarakhand Movement (Kumar, 2011; Linkenbach, 2002; Pathak, 1999).

उत्तराखंड महासभा के कार्यकर्ताओं ने रविवार को संसद भवन के समक्ष प्रदर्शन किया। प्रदर्शनकारी मसूरी और खटीमा गोलीकांड के लिए दोषी व्यक्तियों के खिलाफ कार्रवाई तथा पृथक उत्तराखंड राज्य की मांग कर रहे थे। (नभाटा चित्रः के.के. लश्कर)

Appendix 1: list of NEX–GDDP models used

ACCESS1–0	CSIRO–MK3–6–0	MIROC–ESM
BCC–CSM1–1	GFDL–CM3	MIROC–ESM–CHEM
BNU–ESM	GFDL–ESM2G	MIROC5
CanESM2	GFDL–ESM2M	MPI–ESM–LR
CCSM4	INMCM4	MPI–ESM–MR
CESM1–BGC	IPSL–CM5A–LR	MRI–CGCM3
CNRM–CM5	IPSL–CM5A–MR	NorESM1–M

Appendix 2: Projected change in annual average rainfall towards near-future (2021–50), mid-future (2050–80) and far-future (2081–99) periods with respect to the baseline (1971–05) for RCP4.5 and RCP8.5

Districts	2020–50				2050–80				2080–99			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Almora	6–7.6	6.8	8–9.6	9.15	10–13	11.52	16–22	21.54	14–18	16.35	29–35	33.66
Bageshwar	5.6–7.2	6.35	7.6–10	9.65	11–15	12.4	17–24	22.57	17–20	17.87	31–36	35.22
Chamoli	4.0–6	4.96	5.6–8	6.95	7.0–10.0	9.57	15–19	17.8	15–18	16.38	26–31	29.49
Champawat	7.2–8.4	7.71	9.2–13	12.63	12–16	14.82	20–27	26.82	17–22	19.7	36–41	40.37
Dehradun	6.8–8	7.02	5.2–6.8	6.46	7.0–10.0	9.7	15–18	17.81	13.5–15	14.38	27–30	29.95
Haridwar	6–7.6	6.35	5.2–6.8	6.4	7.0–9.0	8.49	15–18	16.92	13.5–15	14.04	28–30	29.68
Nainital	7.6–8.8	7.73	7.2–8.4	8.12	9–13	10.24	17–20	19.22	14–15.5	14.39	27–33	31.51
Pauri Garhwal	6.8–8	7.63	8.8–11.4	11.2	11–15	13.16	18–25	24.57	16–19	17.61	34–39	37.09
Pithoragarh	4.4–6.8	6.39	6.4–8	6.85	7.0–10.0	8.64	16–19	17.1	13–15.5	14.23	24–31	30.17
Rudraprayag	5.2–7.6	7.01	8.8–11.4	11.35	9–14	13.99	21–27	25.11	16.5–20.5	19.22	33–39	38.63
Garhwal	5.2–6	5.74	5.2–6.8	6.75	7.0–10.0	8.8	16–19	17.06	13.5–15	14.83	37–34	29.56
Udham Singh Nagar	8.4–9.6	8.82	9.6–13.2	13.18	11–16	14.99	22–28	27.38	16–20.5	19.19	36–41	40.23
Uttarkashi	4.0 – 6	4.99	4–5.6	4.64	7.0–9.0	7.16	12–16	15.42	13–15.5	13.91	25–28	27.67

Appendix 3: Projected change in annual average maximum temperature towards near-future (2021–50), mid-future (2050–80) and far-future (2081–99) periods with respect to the baseline (1971–05) for RCP4.5 and RCP8.5

Districts	2020–50				2050–80				2080–99			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Almora	1.4–1.5	1.46	1.6–1.75	1.71	2.15–2.35	2.33	3.4–3.6	3.57	2.4–2.7	2.63	4.9–5.25	5.26
Bageshwar	1.45–1.6	1.52	1.7–1.8	1.76	2.3–2.5	2.43	3.5–3.75	3.66	2.5–2.7	2.74	5.1–5.5	5.37
Chamoli	1.5–1.65	1.58	1.7–1.9	1.84	2.4–2.6	2.52	3.6–3.9	3.81	2.65–2.9	2.84	5.2–5.65	5.59
Champawat	1.4–1.65	1.46	1.6–1.75	1.69	2.2–2.4	2.35	3.4–3.6	3.51	2.4–2.7	2.64	5.1–5.4	5.16
Dehradun	1.4–1.55	1.47	1.7–1.8	1.72	2.3–2.5	2.34	3.4–3.65	3.58	2.4–2.7	2.64	5.2–5.6	5.3
Haridwar	1.4–1.5	1.48	1.7–1.8	1.74	2.25–2.4	2.33	3.55–3.7	3.6	2.5–2.7	2.63	5.2–5.5	5.33
Nainital	1.4–1.5	1.42	1.55–1.7	1.67	2.1–2.4	2.26	3.4–3.6	3.49	2.4–2.6	2.56	5–5.35	5.19
Pauri Garhwal	1.4–1.55	1.41	1.6–1.75	1.66	2.1–2.4	2.26	3.4–3.6	3.45	2.45–4–2.75	2.55	4.95–5.15	5.1
Pithoragarh	1.55–1.65	1.48	1.7–1.8	1.74	2.1–2.4	2.33	3.55–3.8	3.6	2.5–2.75	2.63	5.2–5.45	5.33
Rudraprayag	1.5–1.65	1.52	1.65–85	1.76	2.3–2.5	2.45	3.55–3.7	3.64	2.5–2.85	2.76	5.1–5.4	5.33
Garhwal	14–1.55	1.51	1.65–1.8	1.78	2.3–2.5	2.39	3.6–3.75	3.67	2.6–2.85	2.69	5.2–5.55	5.42
Udham Singh Nagar	1.35–1.45	1.38	1.5–1.7	1.61	2.1–2.4	2.24	3.2–3.45	3.37	2.4–2.65	2.52	4.9–5.1	4.98
Uttarkashi	1.5–1.6	1.55	1.75–1.8	1.82	2.2–2.5	2.44	3.5–3.8	3.73	2.65–2.9	2.73	5.35–5.65	5.52

Appendix 4: Projected change in annual average minimum temperature towards near-future (2021–50), mid-future (2050–80) and far-future (2081–99) periods with respect to baseline (1971–05) for RCP4.5 and RCP8.5

Districts	2020–2050				2050–2080				2080–2099			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Almora	1.5–1.65	1.59	1.6–1.85	1.79	2.1–2.4	2.39	3.6–3.8	3.7	2.5–2.7	2.69	5.2–5.45	5.37
Bageshwar	1.6–1.75	1.66	1.7–1.9	1.84	2.3–2.55	2.47	3.6–3.8	3.78	2.6–2.85	2.78	5.35–5.65	5.47
Chamoli	1.65–1.75	1.71	1.75–2	1.92	2.2–2.65	2.59	3.6–4	3.95	2.7–3	2.9	5.6–5.85	5.72
Champawat	1.5–1.65	1.58	1.7–1.9	1.76	2.2–2.45	2.35	3.4–3.8	3.61	2.4–2.75	2.64	5.1–5.3	5.22
Dehradun	1.5–1.65	1.57	1.7–1.85	1.81	2.3–2.5	2.4	3.6–3.8	3.72	2.6–2.75	2.7	5.35–5.55	5.41
Haridwar	1.55–1.7	1.61	1.6–1.9	1.83	2.35–2.5	2.42	3.5–3.8	3.75	2.6–2.8	2.73	5.4–5.6	5.47
Nainital	1.4–1.65	1.52	1.7–1.8	1.76	2.2–2.4	2.32	3.5–3.75	3.63	2.5–2.7	2.62	5.2–5.4	5.29
Pauri Garhwal	1.4–1.65	1.53	1.6–1.85	1.73	2.2–2.35	2.29	3.4–3.65	3.57	2.4–2.6	2.58	5.1–5.3	5.18
Pithoragarh	1.4–1.7	1.61	1.6–1.9	1.82	2.3–2.5	2.42	3.7–3.9	3.76	2.6–2.85	2.72	5.4–5.6	5.46
Rudraprayag	1.55–1.7	1.64	1.5–1.9	1.82	2.35–2.5	2.46	3.7–3.85	3.74	2.6–2.8	2.76	5.35–5.55	5.4
Garhwal	1.5–1.75	1.65	1.65–1.9	1.86	2.4–2.55	2.48	3.7–3.9	3.82	2.7–2.9	2.79	5.4–5.7	5.56
Udham Singh Nagar	1.4–1.65	1.48	1.6–1.85	1.69	2.1–2.3	2.23	3.4–3.6	3.49	2.4–2.65	2.51	4.9–5.25	5.06
Uttarkashi	1.4–1.8	1.7	1.5–2	1.92	2.2–2.6	2.55	3.65–4	3.91	2.7–2.9	2.86	5.4–5.8	5.69

PIK Potsdam Institute for Climate Impact Research

International Climate Initiative (IKI)

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag

EPICC East Africa Peru India Climate Capacities

teri The Energy and Resources Institute

Creating Innovative Solutions for a Sustainable Future