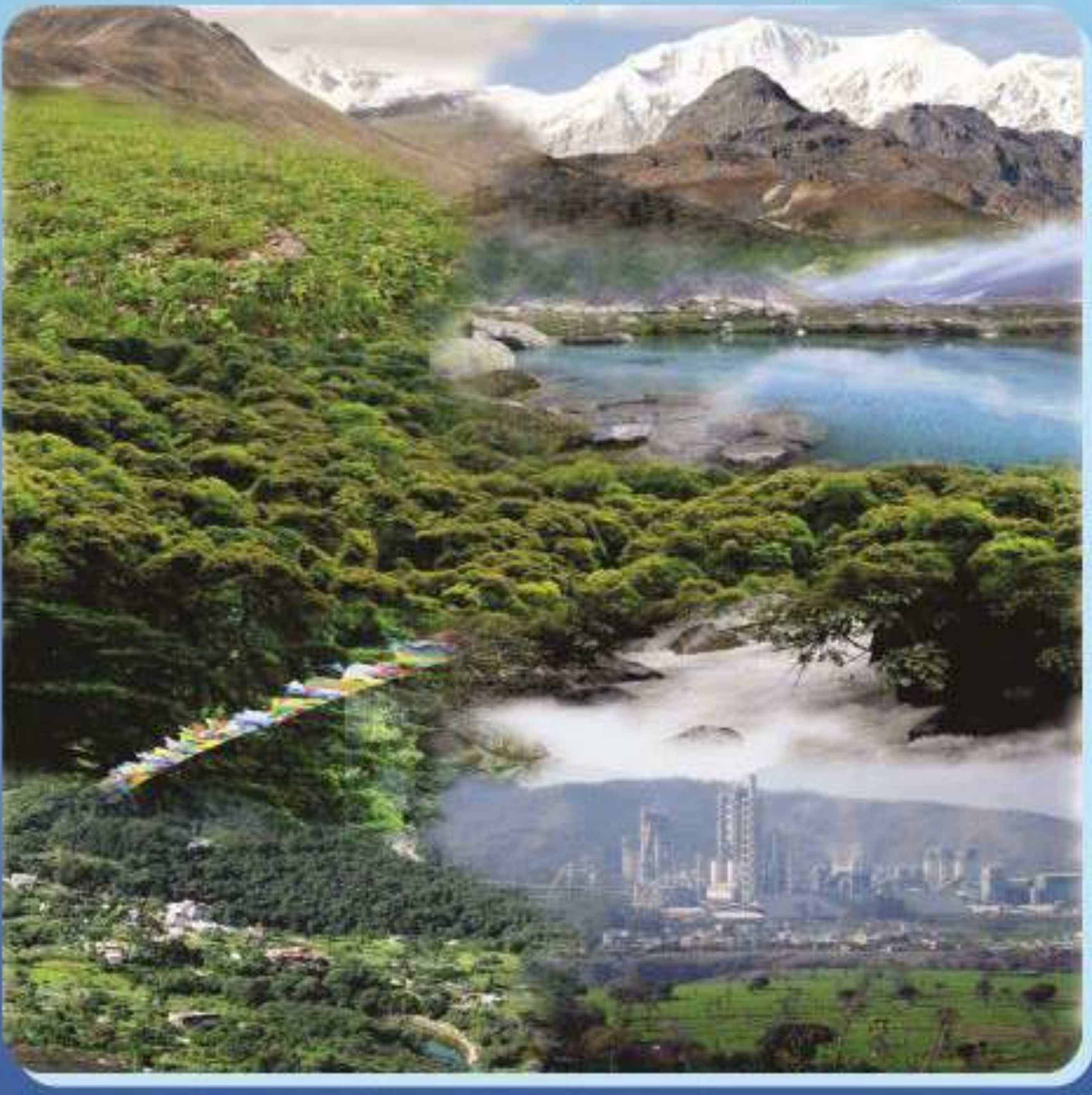
# STATUS OF ECOSYSTEM HEALTH IN THE INDIAN HIMALAYAN REGION

A Report under
National Mission for Sustaining the Himalayan Ecosystem



Government of India
Ministry of Science and Technology
Department of Science and Technology
Climate Change Programme

August, 2019

**Dr. Harsh Vardhan,**
**Hon'ble Union Minister of Science and Technology, Earth Sciences,**
**Health and Family Welfare**

## MESSAGE

The Indian Himalaya Region (IHR) stretches 2500 km across 12 States. It is home to 52 million people and source of food, water and energy for close to 1.5 billion people. The Himalayan ecosystem consists of natural and geological wealth like glaciers, snow, abundant forest cover and bio-diversity, micro flora and fauna and wild life. However the fragile and diverse Himalayan ecosystem is highly susceptible to natural hazards that arises concern about current and potential climate change impacts which include abnormal floods, droughts and landslides, loss of biodiversity and threats to food security. In recent times the receding glacier on account of climate change has aroused global concern as they are source of major rivers. A slight change in the Himalayan ecosystem can drastically alter millions of lives.

In order to understand the complexity of the IHR and unravel the efforts needed to sustain the IHR, a National Mission for Sustaining Himalayan Ecosystem (NMSHE) was launched as one of the 8 national missions under the National Action Plan on Climate Change (NAPCC). NMSHE is the only site specific mission that aims to take appropriate measures for sustaining and safeguarding the IHR. The Climate Change Programme (CCP) of the Department of Science and Technology (DST) is coordinating and implementing NMSHE in collaboration with several central government institutions and the 12 Himalayan States. NMSHE has achieved considerable progress by launching Task Forces, establishing State Climate Change Cells, undertaking capacity building initiatives and building bi-lateral mechanism.

I am delighted to learn that DST is bringing out a "Himalayan Health Status Report" which is basically a summary of the outcome from the six thematic Task Forces.

I would like to compliment the efforts of Climate Change Programme of DST especially Dr. Akhilesh Gupta, Head of SPLICE, and his team in compiling and bringing out a comprehensive report on State of the Himalayan Ecosystem. I am confident, the report will be of great interest and value to reseracher, academicians and policy makers working in the area of Himalayan ecosystem.

(Dr Harsh Vardhan)

**Prof. Ashutosh Sharma**
**Secretary,**
**Department of Science and Technology**

## FOREWORD

Climate change is one of the most compelling global challenges. India being one of the vulnerable countries to climate change in the world a major concern is expressed towards the fragile and diverse Himalayan ecosystem because of potential impacts on the economy, ecology, and environment of the region and areas downstream. The receding Himalayan glaciers, water related hazard and degradation of mountain ecosystems have led to adversities in the livelihood and the environment of the region. It is imperative to understand and act towards minimizing the impacts of climate change on Himalayan ecosystems and the services they provide to people.

On recognition of such dire need the National Action Plan on Climate Change launched eight National Missions out of which two Missions are being coordinated and implemented by the Department of Science and Technology. National Mission for Sustaining Himalayan Ecosystem (NMSHE) is one of them. NMSHE is working to develop in a time bound manner a sustainable national capacity to continuously assess the health status of the Himalayan Ecosystem and enable policy bodies in their policy-formulation functions as also to assist States in the Indian Himalayan Region with implementation of actions selected for sustainable development.

I am pleased to see that the first “State of Ecosystem Health in the Indian Himalayan Region” has been brought out by the SPLICE Division of DST. This report will serve as tool to gauge the status of the vital components of Himalayan ecosystem to understand the current situation and also to try and project what the future holds. I compliment the sincere efforts of my colleagues in the Climate Change Programme, SPLICE Division headed by Dr. Akhilesh Gupta. I am confident that the report will be beneficial to stakeholders, researchers, students and policy makers working in the field of climate change and Himalayan ecosystem. I am also sure that it will lay a strong base for monitoring of the health of Himalayan ecosystem in future.

(Ashutosh Sharma)

## PREFACE

The Himalayan ecosystem is vulnerable to climate change impacts as well as subjected to severe ecological deterioration due to anthropogenic pressures. This has led to significant disruption in ecosystems leading to shifts in range, migration patterns, seasonal activities and abundance of territorial and marine species, affecting the livelihood of resource-dependent communities. Such threats and uncertainties have undermined the socio-economic development of the Indian Himalayan Region.

The National Mission for Sustaining the Himalayan Ecosystem (NMSHE) being coordinated and implemented by the Department of Science and Technology (DST) is multi-pronged, cross cutting mission across various sectors aimed at enhancing the understanding of climate change, its likely impacts and adaptation actions required for the Himalayas, a region on which a significant proportion of India's population depends on for sustenance and the entire nation draws inspiration from.

NMSHE aims to understand the complex processes affecting the Himalayan ecosystem and evolve suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem. The Mission attempts to address important issues concerning (a) Himalayan Glaciers and associated hydrological consequences; (b) Biodiversity conservation and protection; (c) Wildlife conservation and protection; d) Traditional knowledge societies and their livelihood; and (e) Planning for sustaining of Himalayan ecosystem. For this purpose the Mission has launched 6 thematic Task Forces (TF) i.e. Natural and Geological Wealth; Water, Ice, Snow including Glaciers; Forest Resources and Plant Diversity; Micro Flora and Fauna and Wildlife and Animal Population; Traditional Knowledge System and Himalayan Agriculture.

The Himalayan ecosystems are complex and exposed to a number of stressors which are poorly understood. In order to better understand and effectively manage these ecosystems, there is a need to evaluate their current state and 'health'. In many ways, ecosystem health is analogous to human health that can be monitored using certain vital signs or indicators. A healthy ecosystem is capable of providing the 'essential services' that are extremely important for human well-being. Hence NMSHE has worked towards publishing the first ever report on "State of the Ecosystem Health in the Indian Himalayan Region". The report comprises of a comprehensive and complete assessment of vital components of the Himalayan ecosystems i.e Geo-resources, Water Resources, Forest and Floral Diversity, Wildlife Habitats and Faunal Diversity, Traditional Knowledge System and Himalayan Agriculture prepared by the respective Task Forces.

The objectives behind the report are many. Firstly it intends to collate the knowledge and expand the accessible knowledge base. Though extensive research has been conducted in the last few decades, but the knowledge gathered is scattered, reaches selective audience, is limited to sectors or single disciplines and mostly fails to reach the decision makers. The main objective of the report is to inform the decision makers and assist them in policy oriented task. It also aims to address the knowledge gap to promote more targeted assessments about specific areas of concern. Overall the report seeks to promote science-policy discussions at different levels of the government to improve cooperation between communities, states and countries in managing the health of Himalayan ecosystem.

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## ACKNOWLEDGEMENTS

On behalf of Climate Change Programme, SPLICE Division, I would like to acknowledge with thanks the valuable contribution and inputs received from all the Project Investigators of the six Task Forces under NMSHE for the preparation of the Himalayan Health Status Report.

I am extremely grateful to Prof. Ashutosh Sharma, Secretary DST for supporting to the Climate Change Programme and graciously motivating our efforts.

I would like to thank Dr Akhilesh Gupta, Head, SPLICE, DST for taking lead in successful implementation of various programmes under NMSHE and motivating his team to work on the prepration of the report.

I wish to express heartfelt gratitude to the members of Steering Committee, Expert Committee and Reviewer’s Panel for their continuous support and invaluable insight provided for implementing the NMSHE.

I would also like to thank the scientists of SPLICE/CCP Division in DST especially our colleagues Dr. Susheela Negi Scientist E and Dr. Rabindra Panigrahy, Scientist D for their valuable support. I also wish to acknolwdge support provided by Dr Mustafa Ali Khan and Dr Yangdup Lama of IHCAP, SDC for contributing imensely to the comiplation of inputs.

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## List of Acronyms

| | |
|---|---|
| **IHR** | Indian Himalayan Region |
| **WIHG** | Wadia Institute of Himalayan Geology |
| **GSI** | Geological Survey of India |
| **CBRI** | Central Building Research Institute |
| **CRRI** | Central Road Research Institute |
| **ICIMOD** | International Centre for Integrated Mountain Development |
| **LULCC** | Land Use Land Cover Changes |
| **ISA** | Israel Space Agency |
| **IRSO** | Indian Space Research Organization |
| **CWC** | Central Water Commission |
| **NMSHE** | National Mission for Sustaining Himalayan Ecosystem |
| **NIH** | National Institute of Hydrology |
| **SCA** | Snow Covered Area |
| **NSIDC** | National Snow and Ice Data Centre |
| **HKH** | Hindu Kush Himalayan |
| **GLOF** | Glacial Lake Outburst Flood |
| **PDGLs** | Potentially Dangerous Glacial Lakes |
| **LMWL** | Local Meteoric Water Line |
| **GMWL** | Global Meteoric Water Line |
| **EC** | Electrical Conductivity |
| **TSS** | Total Suspended Solids |
| **COD** | Chemical Oxygen Demand |
| **BOD** | Biological Oxygen Demand |
| **DO** | Dissolved Oxygen |
| **CR** | Critically Endangered |
| **EN** | Endangered |
| **NT** | Near Threatened |
| **IUCN** | International Union for Conservation of Nature |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **RCP** | Representative Concentration Pathways |
| **CMIP5** | Coupled Model Inter-comparison Project 5 |
| **NWFP** | non-wood forest products |
| **TKS** | Traditional Knowledge Systems |
| **TEK** | Traditional Ecological Knowledge |
| **NEPED** | Nagaland Empowerment of People through Energy Developmen |
| **TIS** | Target Intervention Sites |
| **SCT** | Staggered Contour trenches |
| **SALT** | Sloping Agricultural Land Technology |
| **ICAR** | Indian Council of Agricultural Research |
| **IFS** | Integrated Farming System |
| **KVKs** | Krishi Vigyan Kendras |
| **NMSA** | National Mission on Sustainable Agriculture |
| **NTFP** | Non-timber Forest Products |

# Executive Summary

The National Mission for Sustaining the Himalayan Ecosystems (NMSHE) is one of the eight ambitious missions set up by the Government of India to combat the adverse impacts of human induced climate change in the region. This mission, being led by the Department of Science and Technology (DST), focusses on the Himalayan Ecosystems which provide numerous ecosystem services to the millions of the people in the Indian sub-continent and but extremely vulnerable to degradation. One of the outputs of this mission is to bring out the status of ecosystem health in this region based on scientific methods, using reliable indicators.

This report is based on a comprehensive assessment of ecosystem health in the Indian Himalayan Region (IHR) done by six task forces (TFs) under NMSHE, viz., Wadia Institute of Himalayan Geology (WIHG), National Institute of Hydrology (NIH), G.B.Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Wildlife Institute of India (WII), Jawahar Lal Nehru University (JNU) and Indian Council of Agricultural Research (ICAR). These Institutes have undertaken the assessment of Himalayan ecosystem health in six thematic areas viz., (i) Himalayan Glaciers and Geological Resources, (ii) Water Resources and Hydrology, (iii) Forests and Floral Diversity, (iv) Wildlife Habitats and Faunal Diversity, (v) Traditional Knowledge Systems, and (vi) Agroecosystems and Farming Practices by the respective Institutes.

The assessments have been done at various spatio-temporal scales depending upon the current state of knowledge on various themes. In addition, each TF has undertaken basic research at various scales in the IHR and come up with quantitative information and baselines. Under each theme a few reliable indicators have been selected for the assessment along with specific methods with a view to repeat the assessment at regular intervals in future. Key findings under various thematic areas are as follows:

i. There are around 9,575 big or small glaciers in the IHR with an estimated ice cover of about 36,000 $km^2$ and overall ice volume of about 2,000 $km^3$. Most of the glaciers in the region are retreating at varying rates. It is estimated that overall there has been 16% recession in the glaciers in IHR since 1960’s. The study reveals that in recent decade frequency of landslides and erosion has increased considerably which may be attributed to extreme weather events. Impacts of climate change on fresh water availability, land use and land cover have been discussed.

ii. The precipitation trends in various river basins of IHR are not consistent. The Kashmir region shows a decrease in number of rainy days as well as overall annual precipitation since last 30 years. However, Chenab and Satluj basins show an increasing rainfall trend. The state of Uttarakhand show very high fluctuation in summer precipitation.

Similarly, trends in snowfall and snow cover do not show any appreciable increasing or decreasing trend in IHR. Many rivers and springs in the IHR show decline in flow and volume of water which may be attributed to combined effects of anthropogenic and climatic factors.

iii. Overall forest cover in the IHR is 32.48%. There has been a slight increase in per cent cover of the forests in the Himalayan states but the North-eastern hill states exhibit slight decrease in cover. The IHR harbours nearly 8000 species of vascular plants that forms nearly 47% of Indian Flora. As per the assessment done by IUCN (2016), Eastern Himalaya have higher number of threatened species (1139) as compared to Western Himalaya (411). Within the intensive survey localities (vertical transects) the range of species richness is lower (13-29) in Western Himalaya as compared to Eastern Himalaya (23-47). The regeneration status of tree species was found better in Teestavalley as compared to Bhagirathi valley. The Himalayan region is infested with a total of 190 invasive alien plant species. *Partheniumhysterophorus*, *Lantana camara*, *Mikaniamacrantha,* and *Ageratinaeupatoria*are most noxious invasive species that are rapidly replacing the native vegetation thereby affecting the health of terrestrial ecosystems.

iv. Status of wildlife habitat (Habitat Quality) and their use by key faunal species were assessed at three scales viz., Pan-Himalaya, 5 states, and one river basin using varying grids (16 x 16 km grids for Pan-Himalaya and 4 x 4 km for states and river basins) coupled with remote sensing data as well as ground based information on biotic, anthropogenic and physical factors.Majority (56%) grids in the entire IHR showed moderately degraded habitats, whereas 27% grids show near natural status. Few (17%) grids are highly impacted with poor ecosystem health. Most of the degraded grids are at lower elevations closer to human habitations. In both Western and Eastern Himalaya, high altitudes (>3000m asl) exhibit better habitat conditions for key faunal species. Aquatic and wetland habitats at higher altitudes are most threatened owing to intensive land use practices, diversion of water and rapid infrastructure development.Barring a few pockets of Protected Areas, at the Pan Himalayan scale, the entire subtropical belt of Western Himalaya depicted poor ecosystem health indicates need of immediate management interventions.

v. The Task Force on Traditional Knowledge System (TKS) is currently in the process of documenting the traditional knowledge among selected indigenous ethnic communities (IECs) across IHR. The TF is also assessing the trends in the status of TKS among the study communities in terms of Health Care Systems, Food habits, Farming Practices, Natural Resource Use and Management, Housing Pattern, and Culture. A case study on the status of TEK among two communities, viz., Barpatiyaand *Van Rajis* in District Pithoragarh of Uttarakhand has been presented. The study reveals that Barpatiyas still retain more than 80% knowledge on traditional farming practices, upkeep and cleanliness of water courses and use of wild medicinal herbs. On the other hand Van Rajis have recently adopted farming practices and their TEK is eroding rapidly. Implications of these trends are discussed in the light of climate change adaptation and flow of ecosystem services to these communities. Based on the current level of data available to the TF, it is too early to link the TEK with ecosystem services vis a vis health of ecoystems in and around the settlements of these communities.

vi. The IHR contributes to about 15-18% of agricultural production. However, owing to harsh climatic conditions and limited cultivable area overall yield is much less (1680.58 kg/ha) compared to national average (2984 kg/ha). Overall health of soil in the region is on decline due to erosion and lack of management. Climate change in the Himalayan region poses new challenges to agriculture, animal husbandry and food security. In order to achieve climate resilience, out of 183 districts of IHR, agricultural contingency plans have been prepared for 112 districts by National Initiative in Climate Resilient Agriculture (NICRA) to guide the farmers in the present unpredictable climatic scenario. Along with this, the Task Force on Himalayan Agriculture is also deeply devoted in making the Himalayan farmers' climate smart in 15 pilot sites and 18 target intervention sites (TIS) ranging from 154 m asl in Nagaland to 4480 m asl in Leh.

Present assessment underlines need for an integrated and interdisciplinary approach to management of Himalayan Ecosystems. Baseline data generated for various thematic areas need to be archived and entered in an interoperable database for future monitoring. Frequent meetings of all Task Forces and State Climate Change Cells and Policy planners would be needed in order to streamline the research, management and long term monitoring of the bio-physical and socio-economic parameters so as to sustain the Himalayan ecosystems and enhance the resilience of local communities.

# 1 Geo-resources

## 1.1 Background

The Himalaya is the very vast ground-base for the source of human prosperity due to its forests, minerals and water resources. It houses hundreds of rivers supplying water to a huge land and population throughout the year. The altitudinal diversity of the Himalayas attribute to the climatic diversity of the region. Over the past few decades, changes in climate and local weather condition have made a substantial impact on the area, in term of structure and characteristic. These changes are are evident from shrinking of snow cover, glaciers, upward shifting of snow line & vegetation, depletion of water in springs, change in rainfall pattern, loss in biological productivity, extinction of plant and animal species and enhancement of extreme weather events etc. Hydrological imbalances currently observed in the Himalaya are considered to be linked to the loss of vegetation cover. Further, the geomorphological factors in geologically active belts aggravate the process of landslides and erosion. These phenomena directly deteriorate the local environment, and have significant implications for the adjoining regions. This chapter comprises of the state of knowledge and research on the health of the Himalaya and its subsequent impact on natural geological resources and related key sectors.

Himalaya is young and tectonically active and formed as a result of massive collision between Eurasia and the northward-drifting Indian plate about 50 million years ago. The Indian Himalayan Region (IHR) is well known for alpine meadows, river valleys, lake basins, cold deserts, inter-mountain valleys, deep gorges, snowfields, glaciers and alluvial plains. It exerts a considerable influence on weather patterns throughout the South Asia. The Higher Himalaya houses the largest and most important glacier systems in the world. These glaciers feed majority of the rivers originating from the Himalaya and thereby form the life-line for the millions of people living in their lower basins. Water supplied by the mountain aquifers in the form of springs is also vital for sustaining domestic livestock and agricultural activity since the ancient times. The current precipitation conditions with increased run-off and less infiltration, coupled with removal of forest cover, has resulted in depletion of hill aquifer system in the IHR. The landslides and related mass movements are common in the Himalayan terrain, and are result of one or more of the reasons like geologic, geomorphic, and anthropogenic and geotechnical characteristics of the slopes. The landslides and mass movement activities particularly along Char Dham Yatra route cause disruption to the entire community system. The minable minerals also impact on the ecosystem either by the operational mining in a fragile ecosystem or their alteration and decay that causes chemical impact on the biodiversity.

## 1.2 Methodology

The standard methodology for the collection of primary and secondary data was adopted in the present work. Though plenty of information is available on the geological wealth of the Himalaya and the exogenic processes like landslides, cloudbursts, weathering and erosion etc., this information and data were scattered and are available in different format. The first task was to collect all the information in a standardised format and accordingly all the secondary data were collected and compiled from the published literature and reports. All the data were standardised so that it could be used in the GIS format for further analysis. However, there remains certain gap in the compilation of database for which collection of data directly from the field is required and is being undertaken in due course of time. Selected field survey was undertaken in the mine clusters in Bageshwar District of Kumaun, Uttarakhand. In the first phase of the project, the emphasis was given to the preparation of a database for the north-western Himalaya covering the states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand.

The sensitive geological indicators selected were glaciers, springs, landslides and mines. Database and thematic maps of geological resources (spring availability, snow cover/glaciers) and processes (mass movements) are being prepared under different climate (temperature and precipitation) scenarios in space and time. Since resources (such as snow cover) and exogenic processes (such as mass movements) are dynamic processes, a time frame of about 10 year's gap (for example 2006 and 2016) is proposed for the assessment. The data base will be valid for the assessment year such as 2016 -17 and would require periodical assessment in future. Map and database of the different minerals and impact of mining activities on the Himalayan ecosystem along with impact of geological processes on ecosystem under different climate scenarios is proposed to be assessed. Adaptive measures and mitigation strategies may be considered for coping with the impact of extreme climate change in IHR which may impact health livelihood, and socioeconomic conditions of the inhabitants. Web dissemination of data base and information generated in the project are useful for the purpose

## 1.3 Status and Trends

### *1.3.1 State of glacier changes and their subsistence in the Indian Himalaya*

Himalayan Cryosphere with their glaciers have aptly been termed as 'Third Pole'. Glaciers are dynamic, self-regulating and highly sensitive to the changes in climate. With around 9,575 glaciers, big or small, within the jurisdiction of the Indian state: an estimated glacier ice cover of about 36,000 $km^2$ and an overall volume of ice of the order of 2,000 $km^3$, means a considerable quantity of fresh water locked in the form of ice. The glaciers in the Himalaya feed 10 major rivers supporting livelihood for about 1.4 billion people whose very survival depends on glacial fed rivers. The current trends in glacial retreat show that most of the

Himalayan glaciers are retreating with a rate fluctuating between 05 and 20 meter per year and thinning by 0.15 to 1.0 meter per year and is significant as it is estimated that the average ice thickness of the Himalayan glaciers (5-10 km$^2$) is 60 to 65 m.

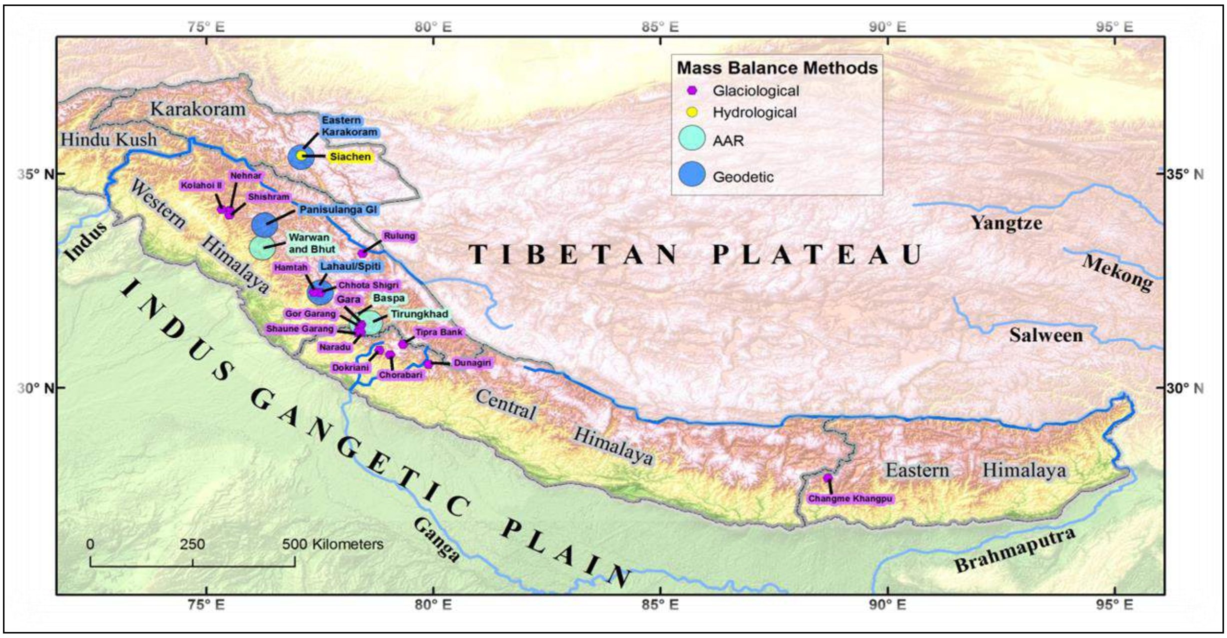


**Figure 1.1 Location of glaciers studied for mass balance estimation for Indian Himalaya.** ***(Source;Pratap, 2015)***

### *a) Length Change variation*

The Geological Survey of India, Wadia Institute and other scientific Indian organizations have at their disposal almost 100 years of well-documented recession records of the lengths of selected Garhwal and Kumaun glaciers, such as Gangotri (1842–2006), Meola (1912–2000) and Milam (1906–97) glaciers (Figure 1.2, Table 1.1,). Gangotri, Dokriani, Chorabari and Chotta Shigri Glaciers have been surveyed extensively by several researchers working on mass balance, hydrological, geomorphological, and isotopic and glacier recession. A study by Mayewski and Jeschke (1979) indicates that Himalayan glaciers have been receding since 1850. The length recession records of Himalayan glaciers indicate that glacier retreat is irregular in extent and rate.

Overall, the recession of the glacier tongues has accelerated since the 1960s. For instance, in Bhagirathi basin, Dokriani Glacier retreated at the rate of 16.5 m/year during 1962–1991, 17.8 m/year from 1991 to 2000, and 15.7 m/year for the periods of 2000–2007 (Table 1.2; Figure 1.2; Dobhal el al., 2008). Chhota Shigri Glacier in the Chandra basin retreated 27.5 m/year from 1962 to 1989, and 53 m/year during 1988 to 2003 (Kulkarni, 2007). Available fluctuation records of Indian Himalayan glaciers suggest that, for north and northeast-facing glaciers in the Bhagirathi basin, such as Gangotri and Meru glaciers, the recession rate fell after 1990, whereas the Parbati and Bara Shigri glaciers are retreating dramatically. Commonly, south, southeast and southwest facing glaciers, such as Jaundhar, Jhajju and

Tilku glaciers in the Tons Valley, have receded rapidly at a rate of 34.1, 15.3 and 13.4 m/year respectively between 1962 and 2010 (Mehta *et al*. 2013). Measurement of snout positions of the Tipra and Rataban glaciers from 2002 to 2008 indicates an enhanced annual retreat of 21.3 and 21.2 m/year, respectively (Mehta *et al*. 2011). Kulkarni *et al*.,(2011) carried out retreat of 1868 glaciers in 11 basins distributed in the Indian Himalaya and estimate an overall reduction in glacier area from 6332 to 5329 km$^2$ from 1962 to 2001/2 – an overall deglaciation of 16%.

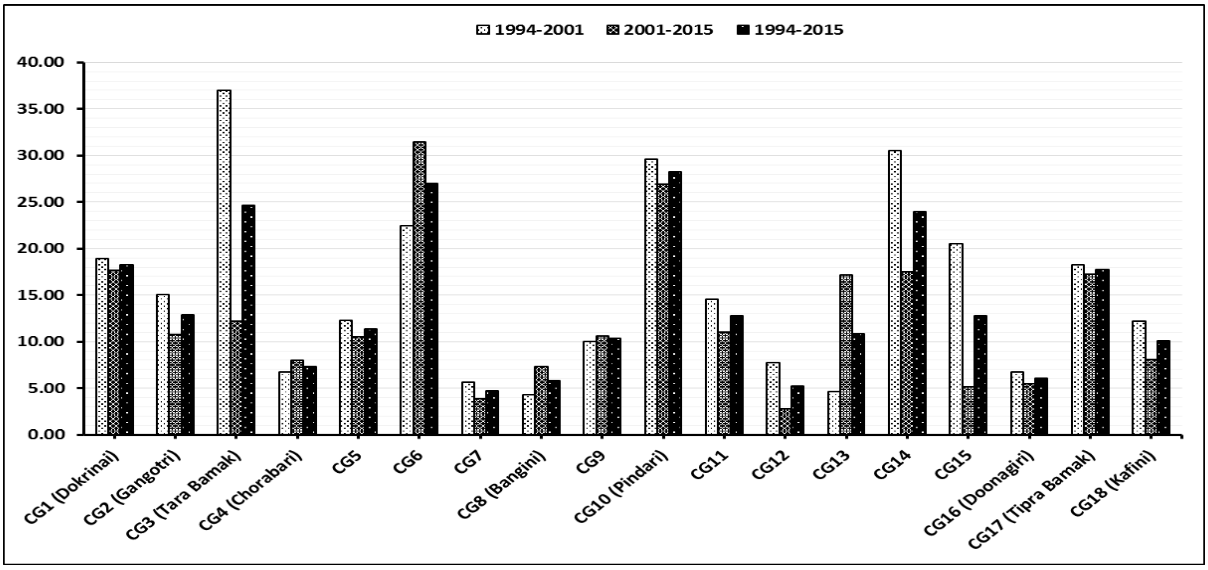


**Figure 1.2 Length changes of selected glaciers in central Himalaya during the period from 1994- 2025 (Garg *et al*., 2017).**

***b) Mass balance trends***

The field base mass change measurements of the Indian Himalayan glaciers are available for 10 glaciers in the western Himalaya, 4 glaciers in the central Himalaya and one in the eastern Himalaya only after 1975 (Table.1.2). The studies reveal that most of the studied glaciers have been continuously losing mass at a variable rate. It is observed that during 1975 to 1980, these glaciers show a mean annual specific mass balance of -0.31 m w.e. a$^{-1}$ (5 glaciers average), similarly -0.41 m w.e. a$^{-1}$ (11 glaciers average) during 1981-90 and -0.906 m w.e. a$^{-1}$ (4 glaciers average) during 2001-2010. However, during 1993-2000 (with gap years 1996 and 1997) shows a net loss of -0.39 m w.e. a$^{-1}$ ice. The decadal analysis indicates that the first decade of the 21st century (2001-2010 and 2011-12) has enhanced in the rate of mass loss compared to the second half of the last century. Cumulative specific mass loss observed over different regions of the Indian Himalayan glaciers shows negative mass balance trend since the first in-suit measurement conducted in 1974. Mass balance was estimated in the years 2001, 2002, 2004 and 2006 for 19 glaciers in the Baspa basin using remote sensing data. Overall specific mass balance in the hydrological years 2000–01, 2001–

02, 2003–04 and 2005–06 were estimated as –90, –78, –57, –50 cm, respectively (Kulkarni *et al*., 2011).

**Table 1.1. Retreat trends of glacier snouts of the Himalayan Glacier, Surveyed and monitored in different time periods**

| Name Glacier | Observation Period | No of year | Total Recession (m) | Average Rate (m/y) | Reference |
|---|---|---|---|---|---|
| Kolai (J&K) | 1912-1961 | 49 | 800 | 16.3 | Vohra 1981 |
| Nehnar (J&K) | 1979-2010 | 31 | 263 | 8.4 | Bhat and Ahmad,2013 |
| Chhota Shigri (HP) | 1987-1989 | 3 | 54 | 18.5 | Kumar and Dobhal, 1994 |
| Bara Shigri (HP) | 1965-2014 | 49 | 1100 | 22.4 | Chand *et al*.,2017 |
| Triloknath (HP) | 1969-95 | 27 | 400 | 14.8 | Swaroop &Shukla,1999 |
| Sonapani (HP) | 1909-1961 | 52 | 899 | 17.2 | Vohra 1981 |
| Bandarpunch (U.K.) | 1960 - 1999 | 39 | 995 | 25.5 | Shukla, *et al*., 2000 |
| Jaundar (U.K.) | 1975-2010 | 35 | 1399 | 40.0 | Mehta, *et al*., 2012 |
| Jhajju(U.K.) | 1962-2010 | 48 | 700 | 13.4 | Mehta, *et al*., 2012 |
| Gangotri (U.K) | 1935 - 2004 | 69 | 1519.13 | 22.0 | Vohra,1981 |
| Dokriani (U.K.) | 1962-2007 | 45 | 751.35 | 16.7 | Dobhal and Mehta, 2010 |
| Chorabari (U.K.) | 1962-2010 | 48 | 327 | 6.8 | Dobhal, *et al*.,2013 |
| Satopanth(U.K.) | 1962-2006 | 44 | 1163.65 | 26.4 | Nainwal *et al*., 2008 |
| Bhagirathi Khk(U.K.) | 1962-2005 | 44 | 320.8 | 7.20 | Nainwal *et al*., 2008 |
| Tipra (U.K.) | 1962- 2008 | 46 | 663.0 | 14.4 | Mehta *et al*, 2012 |
| Dunagiri (U.K.) | 1994-2015 | 21 | 128.2 | 6.1 | Garg et at.,2017 |
| Poting (UK) | 1906-1957 | 51 | 262. | 5.2 | Vohra, 1981 |
| Pindari (U.K) | 1845-1966 | 121 | 2840 | 23.4 | Vohra, 1981 |
| Kafni (UK) | 1976-2009 | 33 | 518 | 15.7 | Kumar & Dobhal 1994 |
| Milam (U.K.) | 1849-1997 | 148 | 2471 | 16.7 | Shukla, *et al*., 2001 |
| Shankulpa (U.K.) | 1881-1957 | 76 | 518 | 6.8 | Vohra, 1981 |
| Zemu(Sikkim) | 1977-1984 | 07 | 193 | 27.5 | Vohra, 1981 |

In addition, on a regional level, the geodetic studies suggest that on the entire western, the central and the eastern Himalaya experienced vast thinning during the last decade Conversely, Karakoram region showed slight mass gain during similar period. In general, Himalayan glaciers are under thinning (Mass loss) and reduction of length and area in the present climate conditions. However, the recession rate and the amount of mass loss of Himalayan glaciers vary with glacier to glacier depends on the geographical location and climatic regime. Whereas, the trend is always similar shows the susceptibility of precipitation and similar behaviour of Himalayan glaciers. The orientation of glacier seems to have profound influence on snow line altitude. The average altitude of snowline at the end of ablation season is 5400 m for south and 5297 m for north facing glaciers. Area altitude distribution of glaciers also influences mass balance. As mid-altitude changes from

5000 to 5400 m, specific mass balance also changes from –111 to –49 cm (Kulkarni *et al*., 2011).

**Table 1.2. Annual specific balance and mass loss of the Himalayan glaciers in different regions of India (source 1)*Raina and Srivastava (2008); Raina (2009); 2) Dobhal et al. (2008); 3) Dobhal et al.( 2013)***

| Glacier Name | Period of observation | Glacier area $km^2$ | Specific balancem w.e. $a^{-1}$ | Net mass bal. $10^6 m^3$ w.e. $a^{-1}$ | Region | Ref. |
|---|---|---|---|---|---|---|
| Neh Nar | 1975-1984 | 1.25 | -0.54 | -0.67 | Kashmir | 1 |
| Gara | 1974-1982 | 5.19 | -0.37 | -1.94 | Himachal | 1 |
| Gor Gorang | 1976-1984 | 2.02 | -0.43 | -0.87 | Himachal | 1 |
| Shaune Gorang | 1981-1991 | 4.98 | -0.4 | -2.0 | Himachal | 1 |
| Dunagiri | 1984-1990 | 4.39 | -0.60 | -2.66 | Uttarakhand | 1 |
| Dokriani | 1992-2000 | 7.00 | -0.32 | -2.25 | Uttarakhand | 2 |
| Chorabari | 2003-2010 | 6.60 | -0.73 | -4.4 | Uttarakhand | 3 |
| Changme Khangpu | 1979-1983 | 5.6 | -0.27 | -1.5 | Sikkim | 1 |

During a decade of observation (1974-2013) of mass balance of eleven glaciers in J&K, Himachal, Uttarakhand and Sikkim positive and negative balances have been recorded. The mass balance measurement period of each glacier is different for the time span between 1975 and 2013 and was estimated by the glaciological method. Across the Himalayan ranges glaciers mass is wasting at variable rates. The annual mean net mass balance of studied glaciers ranges between -0.67 x$10^6$ $m^3$ w.e. $a^{-1}$ and -2.66 x106 $m^3$ w.e. $a^{-1}$ except for Chorabari Glacier i.e -4.4 x$10^6$ $m^3$ w.e. $a^{-1}$ (Table 1.2). Nevertheless, various estimates based on in-situ and satellite glacier mass balance in the entire Hindu Kush-Karakoram-Himalayan (HKKH) region indicate heterogeneous behaviour (Cogley, 2011; Kääb *et al*., 2012; Gardelle *et al*., 2012; Bolch *et al*., 2012). Kääb *et al.,* (2012). It wasreported that the specific balance across the entire HKKH glaciers during 2003-2008 was -0.21±0.05 m w.e. $a^{-1}$ and that thinning rates were 0.66±0.09 m $a^{-1}$ in the Jammu Kashmir region. Gardelle and others (2012) suggest that the specific mass balance of the central Karakoram glaciers was positive (0.11±0.22 m w.e. $a^{-1}$) between 1999 and 2008.

More recently, the monitoring coverage of Himalayan glaciers is improving, but there are still constraints, such as variable retreat rates, less glacier mass-balance data and a lack of long-term in-situ measurement. Therefore, there is a need to understand the widespread distribution of glaciers encounters different climate regime, temperature variation trend over different altitudes, impact of radiation over different parts of the glaciers with debris cover and clean area in the Himalaya.

### *c) Surging Glaciers*

Surging is one of the important parameters to assess the changes in glacier length through its terminal advancement. Glacial surges are short-lived events where a glacier can advance substantially, moving at velocities up to 100 times faster than normal (Frappe & Clarke, 2007). Surging glaciers are clustered around a few areas across the world. About <1% of Earth's glaciers are believed to surge (Jiskoot *et al., 2000)],* but surge-type glaciers are of great importance in understanding glacier dynamics as they undergo periodic changes between rapid and slow flow without an external trigger. At periods of slow flow their velocity is considerably lower than their balance velocity, so mass is added to the higher parts of the glacier and lost in the lower regions. During a surge, ice is transferred from the upper (reservoir area) to the lower part (receiving area) of the glacier (Meier & Post, 1969). In order to comprehend the mechanisms of glacier surging it is important to examine the systematic differences in surge dynamics between regions. Advance of a glacier terminus during surge is a primary indication of most surging glaciers (Fig-1.3).

**Figure 1.3. View of Surging Glacier showing the advancement of termini (snout) of glacier in Shyok**

Changes in glacier lengths and area are temporal patterns of the surging glaciers. Most of the surge-type glaciers are situated in remote locations and logistically difficult for in-situ study, therefore a very less study has been carried so far special in case of the Himalayan regions. In the recent past use of remotely sensed data provides a valuable resource for identification and documentation as well as systematic analysis of glacier surge dynamics and behaviours on a long-term basis.

Karakoram and western part of the Greater Himalaya is the highest of the southwest Central Asian mountain systems. It has the largest concentration of glaciers in mainland Asia and outside high latitudes, with 8 Glaciers over 50 km long and more than 20 glaciers more than 30 km long. The perennial snow and ice cover forms a huge fresh water resource and glacier melt contributes considerably to the Indus and Yarkand Rivers. In the last 100 years, 26 sudden, rapid advances involving 17 glaciers have been reported in the Karakoram region. Another 12 glaciers have features associated with surge behaviour (Tangri *et al*., 2013). The surges in the Karakoram show a wide range and mixture of characteristics regarding frontal advances & rates and mass change pattern.

**Table1. 3. Temporal variations in the frontal part of the Kumdan group and Rimo group of glaciers** *(Tangri et al., 2013*

| Name of Glacier | Limb | Period | Distance shift (in m) | Remark |
|---|---|---|---|---|
| Chong Kumdan | Northern | 1990–1992 | 50 | Retreat |
| | | 1992–1996 | 300 | Surge |
| | | 1996–1997 | 300 | Retreat |
| | | 2004–2005 | 1100 | Surge |
| | | 1997–2009 | 2,278 | Surge |
| | Central | 1997–2005 | 355 | Surge |
| | | 2005–2007 | 955 | Surge |
| | | 2007–2009 | 23 | Retreat |
| | Southern | 1975–1990 | 1,250 | Retreat |
| | | 1999–2000 | 370 | Surge |
| | | 2000–2006 | 96 | Retreat |
| | | 2006–2009 | 400 | Surge |
| Kichik Kumdan | Frontal lobe | 1975–1990 | 750 | Retreat |
| | | 1990–1996 | 33 | Retreat |
| | | 1996–2000 | 900 | Surge |
| | | 2000–2009 | 550 | Retreat |
| Aqtash | Frontal | 1975–1992 | 300 | Retreat |
| | | 1992–2003 | 830 | Surge |
| | | 2003–2009 | 192 | Surge |
| Rimo Group | Northern | 1962–1990 | 1,083 | Retreat |
| | | 1990–1995 | 377 | Surge |
| | | 1995–1997 | 708 | Surge |
| | | 1997–2001 | 34 | Retreat |
| | | 2001–2008 | 19 | Retreat |
| | Southern | 1962–1990 | 129 | Surge |
| | | 1990–1995 | 155 | Surge |
| | | 1995–1997 | 230 | Retreat |
| | | 1997–2001 | 67 | Surge |
| | | 2001–2008 | 82 | Retreat |

A study on temporal variation in the frontal part in the Rimo, Chong Kumdan, Kichik Kumdan and Aqtash glaciers, Shyok valley, Karakoram Himalaya, Ladakh Region has been carried out for the period from 1962 to 2009 by Tangri *et al*. (2013). The study revealed that most of the surging glaciers exhibit a cyclic behaviour. For example the Chong Kumdan glacier, the northern limb advanced 200 m between 1992 and 1996 and then a retreated by nearly 250 m between 1996 and 1997. Thereafter it has continuously advanced for about 2,278 m (between 1997 and 2009). Whereas, the central limb retreated during 1996, 1997, 2000 and 2001 but in general it show an overall advance of about 1,275 m between 1997 and 2009. The southern limb retreated by almost 1,250 m from 1975 to 1990 and again advanced by 370 m between 1999 and 2000. Subsequently, between 2000 and 2006 it has retreat by 96 m (Table 1.3). Likewise, all the study glacier demonstrate that the totality of the glacier is presently advancing and nearly touching the Shyok river features associated with surge behaviour (Tangri *et al*., 2013). The study also suggested that glaciers in the Karakoram show long-term irregular behaviour (Karakoram Anomaly) with comparatively frequent and sudden advances as compared to central and eastern Himalayan glaciers.

### *1.3.2 Landslide and related mass movements*

Landslides and related mass movement activities are a part of normal geomorphic cycle and thus are common in the Himalayan terrain. These generally interfere with geologic, geomorphic, anthropogenic and geotechnical characteristics of slopes (Bist and Sah 1999; Paul *et al*. 2000; Bhasin *et al*. 2002; Naithani *et al*. 2002; Sah *et al*. 2003; Gupta and Bist 2004; Gupta and Ahmed 2007; Gupta and Sah 2008; Rana *et al*. 2012; Gupta *et al*. 2013, Gupta *et al.* 2016). These include displacement of slope materials by fall, toppling, slide or flow due to gravity. These along with cloudbursts and outburst floods pose serious threat to the ecosystem (Gupta and Sah 2008).

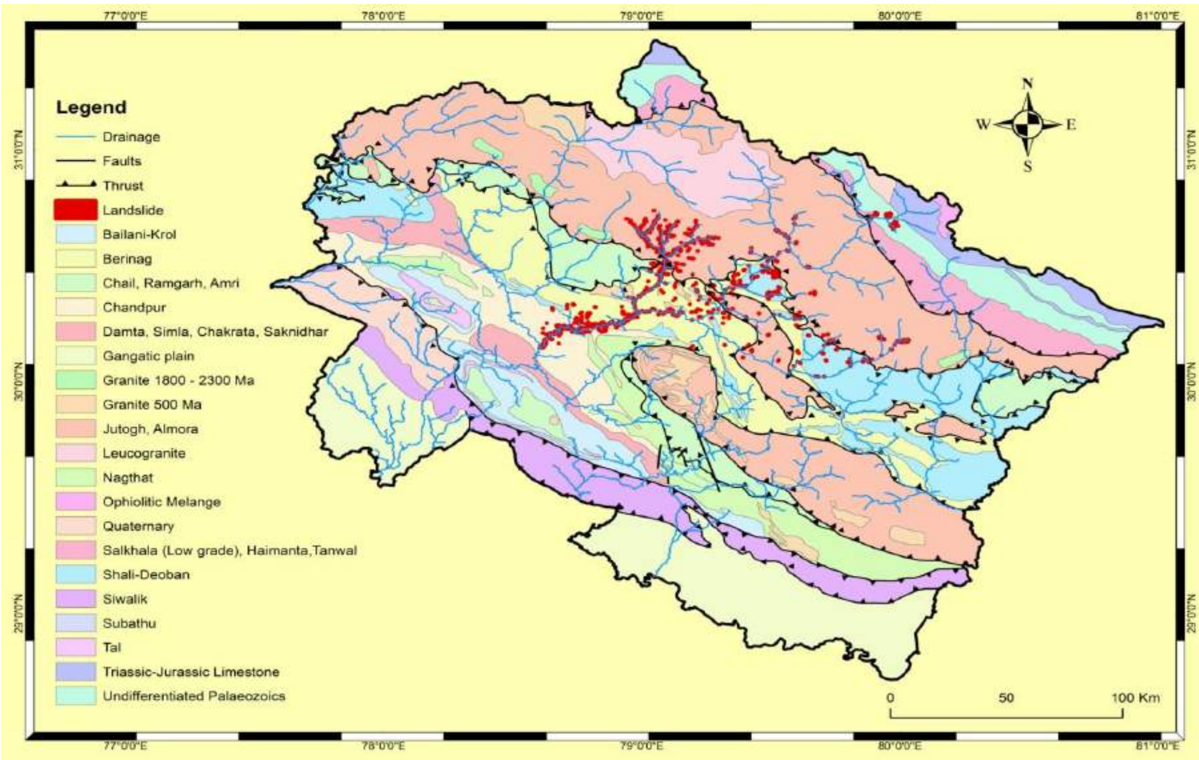


**Figure 1.4. Inventory of landslides for the state of Uttarakhand**

In general, landslides and related mass movement activities are the reflections of various exogenic processes occurring on the surface of the earth. These are affected by natural as well as the man-made factors. Climate change, exhibited by variation in rainfall pattern and frequency and intensity of rainfall, wind, temperature, flood, climate/weather extremes, etc are generally grouped under natural factors, whereas any human intervention on the slopes in the Himalayan regions in the form of construction of roads, tunnels, dams, bridges, hydropower projects, etc falls in the category of man-made factors affecting exogenic processes. All these factors directly or indirectly affect the distribution of landslides in the region.

Landslides and related phenomena are ubiquitous in the Himalayan region, though their magnitude and frequency have been noted to increase during recent times (Gupta *et al*. 2106). These have been studied by researchers from various organizations including Wadia Institute of Himalayan Geology (WIHG), Dehra Dun, Geological Survey of India (GSI), Indian Institute of Remote Sensing (IIRS), Dehra Dun, Central Building Research Institute (CBRI), Roorkee, Central Road Research Institute (CRRI), New Delhi and various universities. The spatial distribution of the landslides in Uttarakhand is presented in Figure 1.4. Some of the examples ofdisastrous landslides in the state of Uttarakhand are August 1977 Tawaghat landslide (Kali valley), 1978 Gangnani landslide (Bhagirathi valley), 1979 Kontha landslide (Mandakini valley), 1980 Gyansu landslide (Bhagirathi valley), 1990 Neelkanth Mahadev landslide (Rishikesh), 1998 Okhimath landslide (Madhmaheshwar valley) (Sah & Bist 1999), 1998 Surabhi Resort landslide in the Mussoorie township (Gupta & Ahmad 2007),1999 Malpa landslide (Kali valley), 2001 Budha Kedar landslide in the Balganga valley (Sah *et al*. 2003), 2001 Phata-Byung landslide (Mandakini valley), 2003 Varunavat Parvat landslide (Bhagirathi valley) (Gupta & Bist 2004; Sarkar & Kanungo 2004) causing great loss of life and property in the region. After the year 2010, and particularly during August 2013, the Himalayan state witnessed a series of landslides after the heavy rainfall and or cloudbursts in the higher reaches (Gupta *et al*2103, Martha *et al.* 2015, Gupta *et al*. 2106). Some of the typical rain induced landslides in the Uttarakhand and Himachal Himalaya are summarized in Table 1.4.

## Table1.4. Depicting major and disastrous landslides in the state of Uttarakhand and Himachal Pradesh

| Sr N | Area / Place | Date | Consequences of heavy rainfall |
|---|---|---|---|
| 1 | Belakuchi, Uttarakhand | July 1970 | Cconsiderable loss of life and property and an entire Belakuchi village was washed away. |
| 2 | Uttarakhand | Sept 1970 | Landslide and house collapse killed 223 people. |
| 3 | Himachal Pradesh | July 1973 | Landslide cut off Shimla from the rest of the country. |
| 4 | BhagirathiValley Uttarakhand, | Aug 1978 | Breaching of lake in Kanldiya Gad, Debrani vill washed away, Manari-Bhali hydroelectric project damaged. |
| 5 | Tawagath, Uttarakhand | Aug1977 | Tawaghat landslide in Kali valley killed 44 people, damaged 100 houses and 2 km road damaged at many places, life was disrupted in an area of $50^2$km. |
| 6 | Mandakini Valley, Uttarakhand | Aug1979 | Killed 39 people 100 cattle, destroyed 150 houses and effected an area of $10^2$km. |
| 7 | Satluj Valley, Himachal Pradesh | Sept1988 | Cloud burst and flash flood along Soldan Khad in Satluj valley killed 32 people, 15 houses, 35 bigha agricultural land, 600 apple trees, 2 km road of NH 22 and 20 m bridge on Soldan Khad washed away. |
| 8 | SpitiValley, Himachal Pradesh, | July and Aug1991 | 1500 m road section of NH-22 and washed away agricultural land of Leo village situated down stream. |
| 9 | Satluj Valley, Himachal Pradesh | Feb 1993 | 500m road section of NH-22 washed Rs. 10 million loss to road and forest land, a village upper slope was in danger. |
| 10 | Satluj Valley, Himachal Pradesh | July 1993 | Lake formed by the blocked of the Satluj river due to Nathpa rockfall damaged Sanjai power house, loss of about Rs. 45 million. |
| 11 | Haridwar, Uttarakhand | Aug 1994 | Landslide at Bhimgora in Haridwar killed 1 child, destroyed 2 houses and 50m rail track and 100m, rail traffic was held for 21 days. Total estimated loss to railway, P.W.D. and private property of Rs. 210 million. |
| 12 | Bhagirathi valley, Uttarakhand | Aug1995 | Cloud burst associated debris flow along Tiloth Nala at Uttarkashi in Bhagirathi valley damaged 200m road section and 18 buildings. |
| 13 | BeasValley, Himachal Pradesh | 4-5 and 12 September 1995 | Flood and landslide along Beas river in Kulu valley killed 65 people, NH-21 damaged at numerous places, loss to government and private property, road and bridges estimated US$ 182 million. |
| 14 | SatlujValley, Himachal Pradesh, | 4-5 September 1995 | Flush flood along Panwai Khad in Satluj valley washed away 19 houses, 3 bushes, HPRTC workshop and damaged HP P.W.D. RH at Tapri. |
| 15 | Pabbar Valley, Himachal Pradesh | 11 August 1997 | Flush flood and landslide along Andra Khad in Pabber valley killed 124 people, 456 cattle, washed away government and private buildings, 200m road section and damaged 500m road and Andra power house at Chirgaon. The loss to property was estimated Rs. 10.63 million. |
| 16 | Himachal Pradesh, SatlujValley | August 1997 | Cloud burst and flush flood along Satluj river killed 19 people, 464 cattle damaged 105 houses, 10 cattle sheds and 39 hector agricultural land. Total loss to property and hydel projects was estimated Rs. 672.9 million. |
| 17 | Mandakini Valley, Uttarakhand | 11-12 and 18-19 August 1998 | Devastating landslide and flush floods in Madhmaheshwar and Kaliganga valley around Okhimath killed 101 people 422 cattle, washed away 820 houses and 411 hector agricultural land, 9752 person in 29 villages effected. The loss to immovable property was estimated Rs. 41 million. |
| 18 | KaliValley Uttarakhand | August 1997 | Cloud burst, flush flood, rockfall and debris flow along Malpa Gad in Kali valley killed 211 people, washed away road section at numerous places in upper part of Pithoragarh district. |
| 19 | Mandakini Valley, Uttarakhand | 16 July 2001 | Cloud burst, landslide and debris flow in Phata and Bung-gad, around 14 village are affected in Kedar valley, Okhimath tehsil, Rudraprayag district, killed 27 people and 53 livestock, more than 24 people injured, 154 houses damage, more than 43 hector agricultural land washed away. 11 km stretch of Rudraprayag-Kedarnath road between Guptakashi-Barasu damaged. |
| 20 | YamunaValley, Uttarakhand | 30 August 2001 | Khanara slide 14 km north of Barkot in Yamuna valley blocked the Yamuna, created lake and damaged 100m road section and interrupted pilgrimage flow to Yumnotri. |
| 21 | Alaknanda Valley, Uttarakhand | 30 August 2001 | Cloud burst in late hours in Guna village of Ghanshyali tehsil killed 7 people, 6 houses completely and 40 houses partially damaged, damage to agricultural land. |

| | | | |
|---|---|---|---|
| 22 | Balganga Valley, Uttarakhand | 10 August 2002 | Cloud burst and debris flow in late hours in Medh and Dharm Ganga valleys, Budha Kedar area, Ghanshyali tehsil, Tehri district. 29 people died and 31 people injured in Marwari, Medh, Agunda and Kot villages, 16 houses completely damaged, loss to live-stock agricultural land and bridges. Micro hydel plant damaged at Budha Kedar. |
| 23 | Kullu Valley,Himachal Pradesh, | 16 July 2003 | Cloud burst and debris flow in late hours in Pulia Nal in Hurla valley washed away three labour camp site of Parbati Hydroelectric Project. 38 people died and around Rs. 10 million loss occurred to property beside damaging the road section of project area. |
| 24 | Kullu Valley,Himachal Pradesh, | 7 August 2003 | Cloud burst and flash flood in late hours along Kangli Nala in Kullu valley washed away 40 labours and injured 17 due to channels shift at labour camp site of proposed Rhotang Tunnel Project of BRO. |
| 25 | Bhagarathi Valley, Uttarakhand | 24 September 2003 | Heavy rain activated the Tambakhani slide in Varnavatparvat along the right bank of Bhagarathi river at Uttarkashi. The slide continued for more than a week. The ingress of rain water through cracks and trenching above the crown on highly weathered phyllites and thick soil cover initiated the slide. Two new slide are created right from 600m high hill slope. Nine hundred houses are damaged and some of the four story buildings at the toe portion of slide are completely buried under sliding mass. About 5000 population was effected. |
| 24 | Isolated landslides in Uttarakhand | 2009 | Heavy rainfall and cloudbursts left > 70 people dead in separate incidents all across the state of Uttarakhand. |
| 25 | Kedarnath Disaster, Uttarakhand | June 2013 | High intensity rainfall and flash flood in the upper reaches of Uttarakhand caused series of landslides in the entire state of Uttarakhand and killed more than 5000 people. |
| 26 | Balia Nala Landslide (Nainital township) | Sept 2014 | High intensity rainfall in the caused landslide long the right bank of the Balia Nala damaging the entire Rais hotel colony locality and the footpath. More than hundred family living in the area was displaced |
| 27 | Stone lay area compound Landslide (Sher-ka-Danda hill) (Nainital township) | July 2015 | Heavy rainfall in the area damaged the link road connecting Birla Vidya Mandir School with the Nainital Town Mall road.Huge debris were brought down on the Mall road as well into the Lake causing serious environmental issues. |

### *1.3.3 Status of Himalayan Springs*

Natural springs are the key source of water security for the Himalayan population. The Indian Himalayan region (IHR) covers about 16.2% of the country's total geographical area and inhabits more than $3.1x10^7$ people. Most of the population living in the Higher Himalaya, Lesser Himalaya, and Sub-Himalaya depend mainly on springs. An initial assessment revealed that 80-90% of the population in Meghalaya, Sikkim, and Uttarakhand depends on springs (ICIMOD, 2015). Thus, springs form the lifeline for the large part of the mountainous population for the survival and sustenance. Rivers flowing in the deep valley limit its use for water utilization and tapping of groundwater aquifers in the Himalayan terrain is often difficult and costly. In the inaccessible regions, human settlements are present nearby the spring sources which fulfil the water demand for drinking, household use, and livestocks. In the non-snow fed and rain-shadow watersheds, springs are the only potable source of water.

Impact of climate change and anthropogenically induced degradation on the sub-surface and spring hydrology has been reported and projected by the researchers. There is an increasing evidence of *drying* of *springs*, reducing discharge and deteriorating water quality in many parts of the Himalayan region. Springs are an important component of the ecosystem, if spring dries up it can lead to an environmental crisis in the form of loss of indigenous flora and fauna and human migration.

**a) Effect of Land Use Land Cover Changes on Springs**

Natural vegetation is characterized by high rates of infiltration as compared to anthropogenically modified surfaces. Removal of vegetation cover and intensified land use can affect surface runoff, evapotranspiration, the storage capacity of the soil, and infiltration processes, thus, affecting the natural water cycle of the region. Changes in the urban, agricultural, or forested area have dramatic effects on the discharges of springs. In the Himalaya, land use land cover changes (LULCC) can result from both the natural and anthropogenic processes; however intense changes result from human impact (Taylor *et al*., 2013). The studies of Semwal *et al*. (2004), Munsi *et al*. (2010), Prokop and Ploskonka (2014), Pant and Rawat (2015) discussed the impact of human activities on the Himalayan ecosystem and support the conclusion that over the period of time, (i) deforestation has increased, (ii) forested area has become fragmented, (iii) plantation and agriculture was found to stabilize terraces, (iv) unplanned road and habitation promotes mass wasting events.

Singh and Pande (1989) discuss the impact of anthropogenically modified land cover on the discharge of springs in the Kumaun region. Conversion of indigenous Oak forest to Pine was found to affect the spring hydrology. Oak forest is recognised to have the higher water holding capacity, infiltration rate and high soil moisture content in comparison to Pine forest. Valdiya and Bartarya (1989, 1991) noticed the decrease of 25-75% in the spring water discharge in the Gaula River basin in the Kumaun Himalaya. Reduced rainfall and deforestation during the period 1958 to 1986 that affect the runoff and erosion dynamics in the basin were found to influence the spring water discharge and stream flow. Tiwari (2008) discussedthe impact of population growth and the degradation of forest land in the Nainital district, Uttarakhand. Table 1.5 shows the status of springs in the lake region of the Nainital region. During the last 30 years, 159 natural springs have completely dried and 50 have become seasonal mainly due to large-scale deforestation, reduced percolation and decreased water generating capacity of the land in the area in the Nainital region. In the Almora region out of 360, 270 springs have been dried up due to land use dynamics and its negative impact on the water cycle Rawat (2009).

**Table 1.5. Status of springs in the Lake region, Nainital (Tiwari, 2008)**

| Micro-watershed | Springs perennial | Springs seasonal | Spring density (No. $km^{-2}$) | Perennial Springs dried | Perennial springs became seasonal |
|---|---|---|---|---|---|
| Nihal | 27 | 06 | 01.69 | 14 | 03 |
| Balia | 56 | 17 | 03.36 | 23 | 07 |
| Nalena | 24 | 15 | 03.22 | 07 | 05 |
| Kuria | 97 | 21 | 04.01 | 51 | 14 |
| Bhimtal | 111 | 29 | 03.73 | 64 | 21 |
| Total | 315 | 88 | 03.20 | 159 | 50 |

**Table1.6. Status of springs in the Kosi River basin, Kumaun Himalayas (Grover, 2012)**

| Micro-watersheds | Total Natural Springs (1991) | Natural Springs Dried (1991-2010) | Natural Springs become seasonal (1991-2010) | Existing Natural Springs (2010) |
|---|---|---|---|---|
| Below 1500 m | 35 | 05 | 09 | 21 |
| 1500-1800 m | 31 | 08 | 10 | 13 |
| 1800-2200 m | 21 | 11 | 05 | 05 |
| Above 2200 m | 20 | 15 | 03 | 02 |
| Total | 107 | 39 | 27 | 41 |

**Table1. 7. Changes in Kosi watershed over the period of 20 years (Tiwari and Joshi, 2012)**

| Parameters | Year 1990 | Year 2010 | % Changes |
|---|---|---|---|
| Total population | 7502 persons | 12776 persons | +70.30 |
| Population density | 188 persons/$km^2$ | 320 persons/$km^2$ | +70.21 |
| Per capita land | 00.10 $km^2$ | 00.07 $km^2$ | -30.00 |
| Land holding size below 1 ha | 85.00% | 93% | -44.64 |
| No. of perennial natural springs | 107 | 68 | -36.00 |
| Density of perennial streams | 3.97 km/$km^2$ | 3.74 km/ $km^2$ | -05.79 |
| Forest to cultivated land | 3.1 ha/ha | 2.3 ha/ha | -25.81 |
| Irrigated land | 18.5% | 15% | -03.50 |

Out of a total 107 springs (Table 1.6)in the Kosi headwater in the Uttarakhand region nearly 39% have completely dried up and more than 20% have become seasonal during the last 20 years (Grover, 2015Table 1.7 shows the statistics of human impact on the land and water resources. Population density in the Kosi headwater has increased from 188 to 320 persons $km^2$ over the last 20 years, which is quite high for the mountainous terrain. Population pressure, deforestation, reduced recharge zone and declining rainfall trends in the Kumaun Himalayas seem to affect the headwater recharging sites (Joshi and Tiwari, 2014). Discharge of Kosi River in its headwater region has declined from 550 $m^3\ s^{-1}$ in 2001 to 220 $m^3\ s^{-1}$ in 2007. Perennial springs in the region are decreasing at a rate of 3 springs/year whereas the non-perennial and dried up springs are increasing at the rate of 1 spring/year and 14 springs/decade. Figure 1.5 shows the trend of changing spring hydrology in Nainital region.

There is a lacuna on the impact of LULC on the spring hydrology in the NE Himalayas. Tambe *et al*. (2012) discuss the impact of climate change on the spring hydrology of the Sikkim region. Authors mention that anthropogenic activities such as deforestation, forest fires, and infrastructure development can adversely impact the spring hydrology in the NE Himalayas.

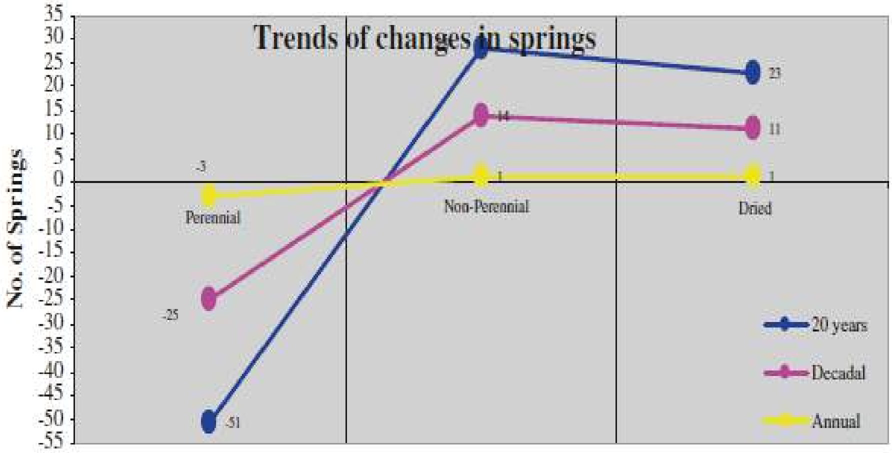


**Figure1. 5. Trends and annual and decadal changes in spring hydrology in the Nainital region (Pant and Rawat, 2015)**

The study of Prokop and Ploskonka (2014) discusses the impact of LULCC on the on the physical and chemical properties of the soil physical and chemical properties in the NE Himalayas over the period of 1930-2010. The plantation was found to stabilize terraces, while deforestation is impacting the fluvial erosion. Since NE Himalayas are important in terms of water resources, focussed research is required to assess the impact of LULCC on spring system.

### *1.3.4 Impact of Mining Activities*

Mining activities are in dispensable for the economic development of any country endowed with mineral resources. This is due to the economic benefits involved in the extraction of mineral resources, mainly in industrial and infrastructural development. Two category of minerals are known to occur the Himalaya: (i) the minerals which were formed as a part of the Himalayan orogeny and (ii) minerals existed in the older crust, reworked during Himalayan orogeny and now emplaced in the Himalayan terrain. Table 1.9 shows a number of various mines distributed in the three states in western Himalaya. Significant reserves of talc, limestone, magnesite occur at several localities in Uttarakhand, whereas mining of limestone, silica boulder and barite is underway in Himachal Pradesh. There are important mineral deposits in J & K states, which includes limestone, gypsum, magnesite and globally known sapphire mine of Paddar. The major mining activities are distributed in the districts of Bageshwar, Almora and Pithoragarh in Uttarakhand, Sirmour Solan and Una in Himachal Pradesh and Anantnag, Baramulla and Udhampur in J & K. The high quality limestone mines of Dehra Dun district were closed because of their impact on the environment, whereas the cost of the phosphorite obtained from underground mines was uneconomic.

Most of the mining activities in Himalaya are located in the Lesser Himalayan belt which has been prevalent since ancient times. The important locations known for old mines in the Himalaya include Shishkhani, Chhanapani, Rai, Burail, Dewalgarh, Dhanpur, Nigote etc for the mining of lead, Sangnam, Harpat Nag, Khanigar, Pokhri, Dhanpur, Dewal Dhar, Askot etc. for mining of copper and Darabi, Chota Shigri etc for zinc. The incline, drive and raises of these mines were made along the ore body, which vary in dimensions and are generally narrow. Their present day depth, however, is narrow, because of land subsidence and wall collapse along the mine wall. Such land degradation processes at times cause a change in landform.

**Table 1.8. Table showing number of various mines distributed in the three states in western Himalaya**

| S. No. | Mines | Uttarakhand | Himachal | J & K | Western Himalaya |
|---|---|---|---|---|---|
| 1 | Total Mines | 91 | 49 | 56 | 196 |
| 2 | Total operating Mines | 60 | 17 | 56 | 133 |
| 3 | Total closed Mines | 31 | 32 | - | 63 |
| 4 | Limestone mines | 02 | 42 | 33 | 77 |
| 5 | Gypsum mines | - | - | 20 | 20 |
| 6 | Talc mines | 85 | - | - | 85 |
| 7 | Magnesite mines | 05 | - | - | 06 |
| 8 | Silica Boulder | - | 05 | - | 05 |
| 9 | Barite | - | 02 | - | 02 |
| 10 | China Clay | - | - | 01 | 01 |
| 11 | Sapphire | - | - | 01 | 01 |

## 1.4 Implications on Georesources

In the Himalaya, three types of river basin exist: (1) rainfed basins, runoff is generated exclusively from rainfall (2) snowfed basins, runoff is generated both from rainfall–runoff and snowmelt (3) glacierfed basins, runoff is primarily generated from the melting of permanent snow fields and glaciers. Natural replenishment of aquifers occurs from both diffuse rainfed recharge and focused recharge via leakage from surface runoff and thus hydrological functioning of aquifers is highly sensitive to changes in climatic conditions, precipitation and evapotranspiration (Taylor *et al.*, 2013).

In the Garhwal Himalayas, Agarwal *et al*. (2012) investigated the long term relationship between rainfall and discharge by studying 50 springs (present in Chandrabhaga and Danda watersheds) in the Tehri-Garhwal region using the daily rainfall and spring flow discharge data over the period of 1999 to 2010. The maximum variation in the spring flow over the period varies from 0.167 to 5.00 L/s. Figure 1.6 shows that with an increase in rainfall, increase in discharge is evident and spring flow discharge slowly diminishes during the non-rainfall months. Figure1.7 explains the dependence of spring flow on the discharge. Springs in the Chandrabhaga and Danda watersheds shows a linear response to cumulative rainfall for the period from June to September (monsoon months) and January to February (winter rainfall months) and nonlinear response from September to January and February to May which is dry months. The immediate and sensitive response of spring flow to rainfall indicates that in the Garhwal region recharge of aquifers is primarily due to rainfall events.

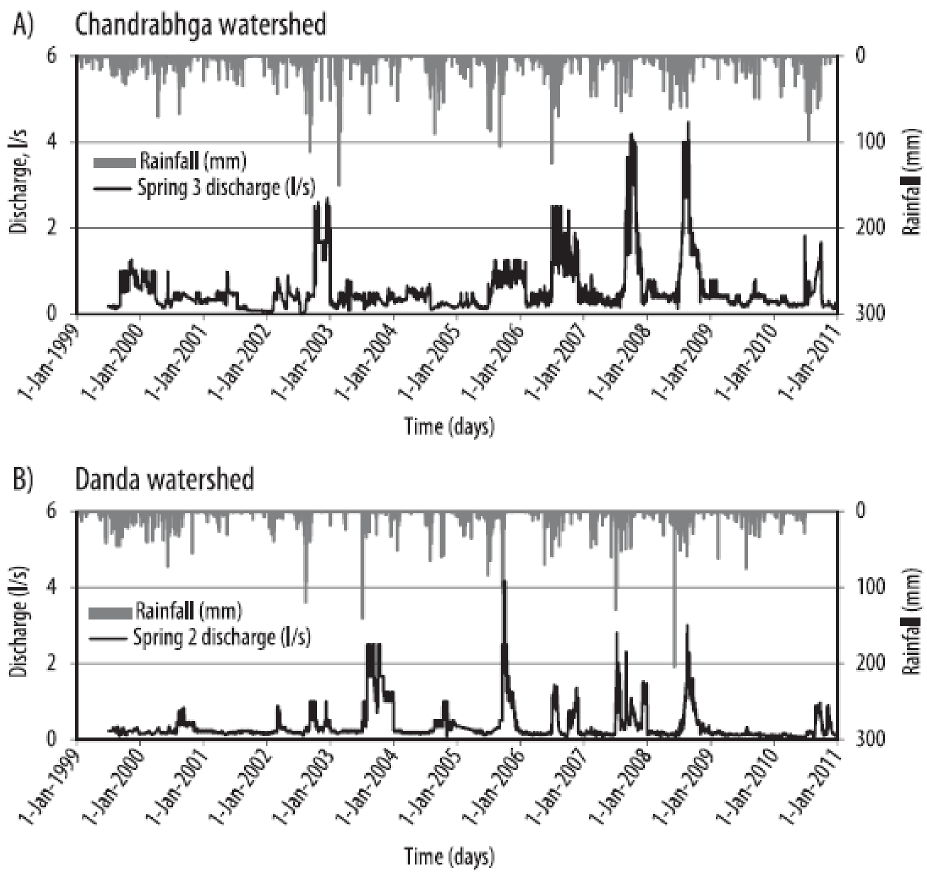


**Figure 1.6. Daily discharge hydrograph for springs in Chandrabhaga and Danda watersheds in the Tehri-Garhwal region *(Agarwal et al., 2012)***

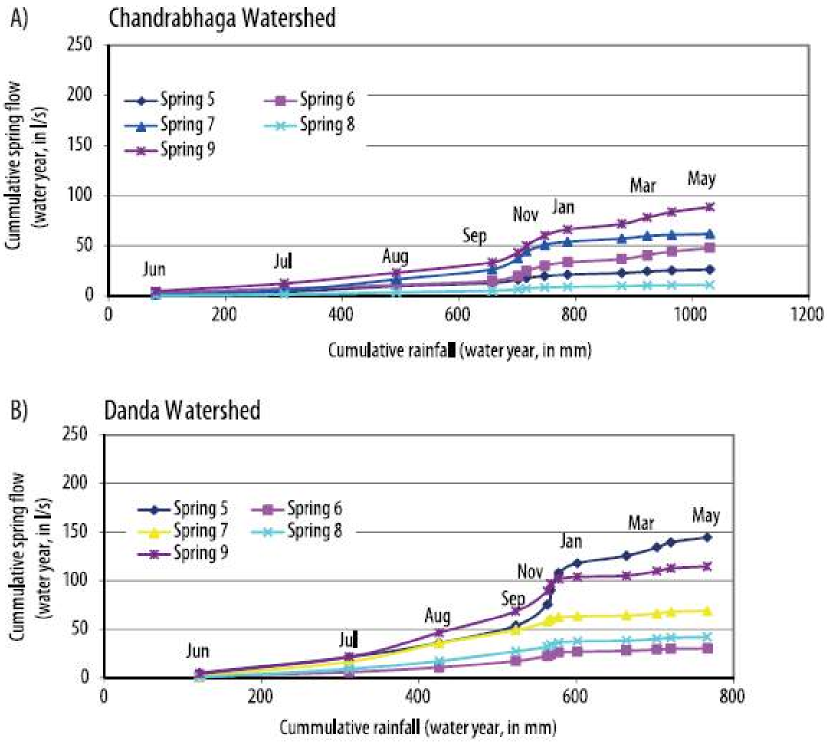


**Figure 1.7. (A) The relationship between cumulative rainfall and cumulative spring flow for five springs in Chandrabhaga watershed (B) Relationship between cumulative rainfall and cumulative spring flow for 5 springs in Danda watershed *(Agarwal et al., 2012)*.**

It has been observed that due to continuously changing climatic conditions rainfall is gradually decreasing in the Kumaun Himalaya. During the last 20 years (1991-2010), the number of rainy days has declined from 60 to 50 and annual average rainfall has decreased from 135 cm to 112 cm with few exceptions in between. The decreasing rainfall has drastically impacted the groundwater storage level in the region. The groundwater storage level in the Kumaun Himalayas is nearly 12% as against the recommended norm of minimum 31% (Rawat, 2009).

In the south and west districts of Sikkim, discharge of springs also shows good correlation with rainfall pattern (Tambe *et al.*, 2012). Figure1.8 shows that in the Sikkim region, spring discharge follows an annual, periodic rhythm that is strongly dependent on the amount of rainfall. The drought prone areas receive little rain during the pre and post monsoon season and thus show dependence on rainfall for the recharge of aquifers. The results indicate that in the scenario of climate change, changing precipitation pattern can adversely influence the discharge of springs in the rain shadow region of the Himalayas.

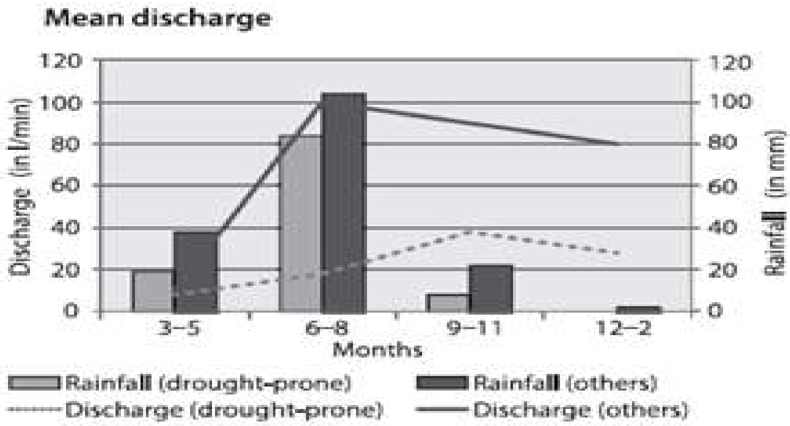


**Figure 1.8. Mean spring discharge and rainfall pattern in Sikkim during 2010-2011** *(Tambe et al. 2012)*

**Table 1.9. Spring discharge expressed as percent of rainfall volume in recharge zone of springs present in Dugar Gad and Srikot Gad (mean values for 1995-1996 to 1999-2000 hydrological years, R=Rainfall, Q= Discharge, values in $10^6$ L)** *(Source: Negi and Joshi, 2004)*

| **Month** | **Ali** | | | **Sainchar** | | | **Srikot** | | | **Barsuri** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **R** | **Q** | **%** | **R** | **Q** | **%** | **R** | **Q** | **%** | **R** | **Q** | **%** |
| Jul | 66.9 | 0.35 | 0.52 | 24.3 | 0.24 | 0.99 | 43.6 | 0.10 | 0.24 | 7.7 | 0.20 | 2.6 |
| Aug | 106.8 | 1.06 | 0.99 | 38.8 | 0.78 | 2.01 | 83.0 | 0.16 | 0.20 | 14.6 | 0.31 | 2.1 |
| Sep | 46.4 | 0.89 | 1.92 | 16.9 | 0.38 | 2.25 | 43.2 | 0.25 | 0.58 | 7.6 | 0.42 | 2.5 |
| Oct | 18.0 | 0.25 | 1.39 | 6.5 | 0.17 | 2.62 | 18.1 | 0.21 | 1.17 | 3.2 | 0.34 | 10.5 |
| Nov | 4.4 | 0.15 | 3.41 | 1.6 | 0.12 | 7.50 | 3.8 | 0.13 | 3.50 | 0.7 | 0.24 | 34.7 |
| Dec | 6.1 | 0.13 | 2.13 | 2.2 | 0.13 | 5.90 | 2.2 | 0.10 | 4.68 | 0.4 | 0.16 | 4.1 |
| Jan | 16.1 | 0.14 | 0.87 | 5.9 | 0.12 | 2.03 | 12.9 | 0.09 | 0.68 | 2.3 | 0.15 | 6.4 |
| Feb | 20.7 | 0.17 | 0.82 | 7.5 | 0.14 | 1.86 | 17.3 | 0.09 | 0.49 | 3.1 | 0.14 | 4.6 |
| Mar | 15.9 | 0.16 | 1.00 | 5.8 | 0.14 | 2.42 | 17.5 | 0.12 | 0.69 | 3.1 | 0.20 | 6.6 |
| Apr | 20.9 | 0.11 | 0.53 | 7.6 | 0.11 | 1.45 | 13.3 | 0.09 | 0.71 | 2.4 | 0.17 | 7.0 |
| May | 18.4 | 0.08 | 0.44 | 6.7 | 0.09 | 1.34 | 5.4 | 0.08 | 1.48 | 1.0 | 0.15 | 14.8 |
| Jun | 50.8 | 0.22 | 0.43 | 18.5 | 0.20 | 1.10 | 27.5 | 0.08 | 0.29 | 4.8 | 0.15 | 3.2 |
| Total | 391.4 | 3.71 | 1.20 | 142.3 | 2.63 | 2.63 | 287.8 | 1.50 | 1.23 | 50.9 | 2.63 | 8.51 |

However, understanding the role of climate in some basins is quite complex. Table 1.8 shows the temporal variation in the spring flow in the Dugar g\Gad and Srikot Gad watersheds in the Kumaun Himalayas. The mean annual spring discharge expressed as percent of total rainfall in spring recharge area was highest in the non-monsoon months of November and December and minimum during the monsoon months (June-September) indicating that a high temperature during the rainy season leads to high evapotranspiration losses of water (Negi and Joshi, 2004). Here it can be stated that apart from rainfall, spring discharge depends directly on the evapotranspiration loss and indirectly to recharge area characteristics such as forest cover, soil type, topography, geology, and biotic interference.

In the Kashmir region, spring discharge shows an inverse relation with precipitation (Figure 1.9). In the year 1995-2005, a decrease of approximately 40-70% in the discharge of springs is witnessed which was positively correlated with the melting of glaciers (Jeelani, 2008). In Kashmir, most of the recharge areas are in uplands and melting of snow and glaciers supports the groundwater system. Using the stable isotope ($\delta^{18}O$ and $\delta^{2}H$) composition of precipitation, snow melt and spring water, Jeelani *et al*. (2017revealed the role of precipitation in maintaining the perennial flow of streams and karst springs in the region and the role of upstream high altitude area as recharging sites. As upstream areas act as a recharging zone, low percolation rate during the cold period results in the low discharge of springs during November to February was observed and rise in the discharge of springs in the summer due to enhanced recharge associated with the melting of snow (Bhat *et al*., 2014). Figure 1.10 shows the annual variation of stream and spring temperature, discharge and precipitation in south eastern Kashmir region. As glaciers are natural buffers of hydrological seasonality releasing melt water the  loss of glacial cover in the Himalayas will have a serious effect on the fresh water availability in the mountainous and downstream regions.

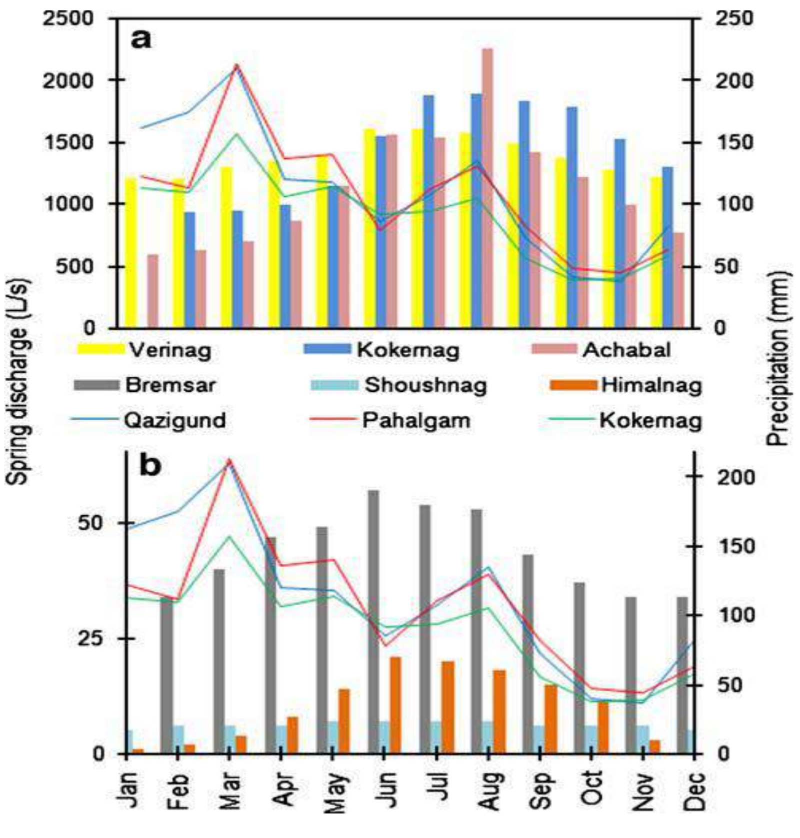


**Figure 1.9. Inverse relation between spring discharge and precipitation and increase in discharge during the period of melting of glaciers over the period 1998-2005 (Jeelani, 2008) (Verinag, Kokernag, Achabal: karst springs; Bremsar: alluvial spring; Shoushnag: Karewa spring and Himalnag: warm spring; Qazigund, Pahalgam and Kokernag (line data): rain gauge stations)**

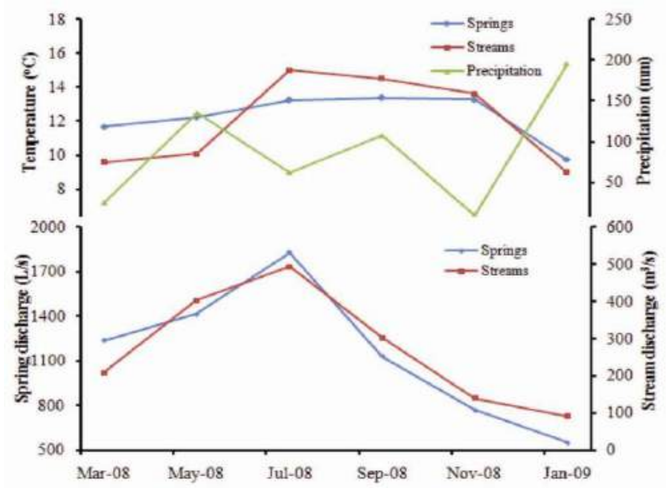


**Figure 1.10. Variation of stream and spring temperature, discharge and precipitation in SE Kashmir region** *(Bhat et al., 2014).*

Climate change can also impact the sub-surface water quality. The study of Taylor *et al*. (2013) and Mikkelson *et al*. (2013) discusses the impact of alteration in physical and biogeochemical processes such as organic matter decay and hydrologic flow paths on the soil and surface water quality. In the projected scenario of heavy precipitation and enhanced runoff, leaching of natural organic matter, dilution of loads and greater pollutant loads from diffuse sources can infect the drinking water quality of springs and groundwater reservoirs (Kundzewicz *et al*. 2008). The review infers that changing climatic trends such as increased rainfall, increased evapotranspiration, and shrinkage of the glacial cover is impacting the spring water discharge and its quality and posing an additional threat to the Himalayan ecosystem. As snow melt generated runoff continues to increase in the projected climatic scenarios, their contribution to potential recharge will likely increase but as snow melt based runoff begins declining, one should expect a decline in runoff as well as groundwater recharge. Immerzeel *et al*. (2010) mention that the effects of climate change on water resources and food security differs substantially among basins and cannot be generalized. Thus, there is an urgent need to study the possible impacts of climatic change on various components of the hydrological cycle at a micro-basin scale.

An updated inventory of the Indian Himalayan glaciers documents large number of smaller glaciers (<1 km$^2$) with their subsistence above 4500 m a.s.l (Shukla and other, 2009). These small glaciers (<1 km$^2$) accounts 66% of the total number, covering 12% of the total glacierized area with only 4% of the total ice volume in the region. However, the larger glaciers (>5 km$^2$) are 7% in number with 60% of the glacierized area and 77% of total ice volume. Further, smaller glaciers lies above the 4500 m a.s.l maintained the microclimate of the high altitude region. Whereas, the larger glacier flow downward to the valley up to 3800 m a.s.l and sustain the cold climate in the valley. Continuous mass loss and recessional rate of larger glacier concurrently increases the number of glaciers due to fragmentation of the tributary glaciers. However, the trunk glaciers that are longer with large ice mass having the recessional rate upto 10-20 $m^{-1}$, eventually will not let the glacier to disappear in a short time period. For example, 30 km of Gangotri Glacier with its average retreat rate during (1962-2006) of 20 m $a^{-1}$ will take ~1500 yr to disappear completely. Still widespread shrinkage of the larger and smaller glaciers in the Indian Himalaya will convert many of the present glacier-fed river systems into rain-fed ones. Less glaciers melt water might affect seasonal water and also results in more pronounced seasonal imbalances of water flows in the downstream of Indian Himalaya.

There is a pronounced effect of climate change on the distribution and the frequency of landslides in the IHR. Of late, it has been noted that there is an evident shift in the climatic factors in the form of (i) increased extreme climatic/rainfall events in the Himalayan region, (ii) more area falling under the influence of rainfall, which were dry otherwise and (iii) the increased frequency of cloudbursts. All these factors have contributed towards increased occurrences of landslides in the Himalayan region. Further, it has been noted throughout the Himalaya, that after 2009 the intensity of rainfall, particularly during monsoon has increased manifold (Gupta *et al.* 2016). Also the century witnessed numerous extreme climatic events. One such event was 15-17 June 2013 when the entire state of Uttarakhand recorded incessant rainfall, and many of the Himalayan rivers, particularly in Uttarakhand, witnessed unprecedented flood causing havoc in the region generating thousands of landslides. Another example of extreme rainfall was the 2005 extreme rainfall events in the Ladakh Himalaya and Maharashtra, 2010 Cloudburst of Leh (Kumar *et al*. 2102) and 2014 floods of Jammu and Kashmir (Mishra 2015).

It has been observed that landslides are generally concentrated along the river valleys, mainly because of the high discharge in the rivers that have been witnessed during last couple of years. Further it has been observed that during the last couple of years, these landslide activities have increased in frequency as well as in magnitude. This may very well be correlated with the shift in rainfall pattern and the higher intensity of rainfall that has been noted particularly after 2010. It has further been observed that there are higher incidences of extreme climatic events during recent past, like one observed in 2013 in the entire north-western Himalaya, causing havoc mainly in the Kedarnath Township, Mandakini valley and further downstream in the Alaknanda valley. The year 2017 also witnessed high concentrated rainfall in many parts of the northwestern Himalaya causing numerous disastrous landslides in the Himalayan terrain. Few to mentions are landslides in the Shimla township, in the Mandi area in Himachal Pradesh and numerous landslides in the state of Uttarakhand, particularly along the *Char Dham Yatra* route, as well as in the Pithoragarh district. The collation of spatial distribution of all the landslides has been carried out for input to the GIS environment (Fig 1.4). Data related to cloudbursts that have been occurring in the Himalayan region have been compiled which suggests that during recent past their frequency has increased manifold, thus posing threat to lives in the region.

Mining involves digging of holes of various dimensions in the ground or the excavation on the wall of the hills that raises doubts its role in the regeneration of the ecosystem. Biodiversity may be damaged in the process and their reclamation is time taking . . It may be noticed that in many cases the infrastructure development for mining (roads, power and settlements etc.) causes more adverse impact than the mine itself. Whilst acknowledging the economic benefits of mining activities there is need to address the environmental hazards that results from mining espicailly in the Himalayan region. Studies have reported that the mining in Himalaya has resulted in degradation of agriculture land (Figure 1.11), inspite of the incidences of land reclamation by the mine owners. There are cases of pollution of varied kinds (air, noise and water).Water pollution and blockage of water channels is reported in many areas due to dumping of the overburden material to the adjacent streams. Few mines are operating along the roadside, which causes destabilizing the hill slopes and triggering the effects of landslides in such areas (Figure 1.12). Efforts for construction of the retaining walls are limited. Cases have been reported in Uttrakhand and Himachal Pradesh where the overburden and mine waste are dumped in the adjacent agriculture land or forest area hindering the prospect of agricutltural and forest activity in the area. Though it is customary for the mine owners to reclaim closed mine area, the practice is rare

**Figure 1.11. Field Photograph Showing the Removal of the Top Soil for Mining in Himalaya**

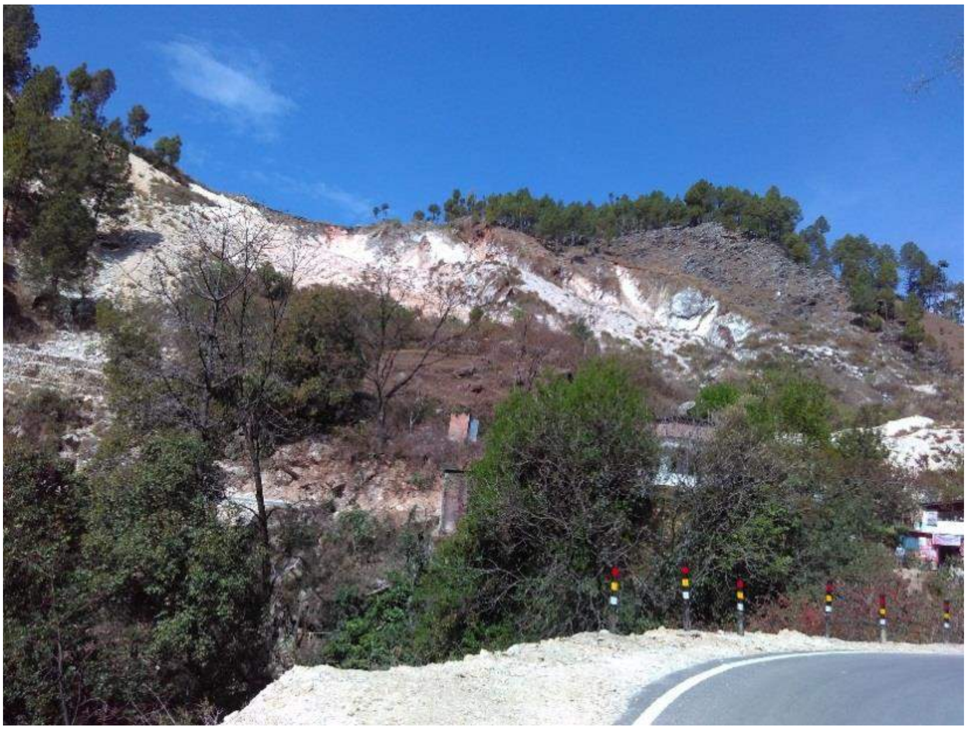

**Figure 1.12. View of the talc mining in Bageshwar (UK) near the road**

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# 2 Water, Snow, and Ice including Glaciers

## 2.1 Background

The Himalayas are drained by 19 major rivers comprising of three major river systems, namely the Indus, the Ganges, and the Brahmaputra. The significance of these three river systems is established by their contribution to more than 60% of annual runoff from all rivers of India that sustains the lives of millions of people living downstream. These river systems consist of substantial contribution from snow and glacier-melt and hold immense potential as a freshwater source for our country. Because of significant snow and glacier contribution, average water yield of Himalayan Rivers is almost double of peninsular rivers. Himalayas have three well-defined hydrological regimes: monsoon dominated regime of north-eastern Himalayas and part of western Himalayas, snow dominated (due to western disturbances) regime of Jammu & Kashmir and cold-arid regime of Ladakh.

Because of its geography, the Himalayan region is particularly vulnerable to the impact of climate change. The rise in mean temperature here has been higher than the global average, and this trend is expected to continue. Glacial retreat is one of the serious concerns in the Himalayas, and this is expected to affect timing, location, and volume of the stream flow. Snow-melt is another factor that affects the availability of water resources, particularly in the lean season. Under changed climatic projections, the rate, volume and timing of melt runoff from the snow and glaciers are likely to be most vulnerable component of runoff for Himalayan Rivers. Therefore, impact of climate change on the melt runoff and change in its temporal distribution needs to be investigated. Also, studies on the trend of changes in hydro-meteorological variables and snow cover over the Himalayan basins need to be assessed along with retreat of glaciers.

For the Himalayan region, long-term ecological and hydrological database are unavailable and there is a need for proper design and operation of hydro-meteorological networks and installion of automated instruments for long-term database development. Understanding of hydrological processes in Himalayan region for optimal utilization of water resources in the present and changed climate scenarios requires application of advanced modelling techniques in conjunction with advanced observations from satellites and isotopic characterization.

Further, there is a need to evaluate the impact of changing climatic variables scientifically as they have great socio-economic-environmental importance. In addition to climate change impacts, tourist and other anthropogenic activities in the Himalayas have increased many fold in recent years resulting in increasing pollution in the pristine rivers and water bodies of the Himalayas.A thorough understanding of hydrological processes in the Himalayan region is necessary for optimal utilization of water resources in present and changed climate scenarios. Recently developed modelling tools need to be applied in conjunction with historical/current observations and projected future climate scenarios to calibrate and validate the models with historical observations and plan adaptive strategies for changed climate situations

Mountains are more susceptible to climate change and mountain regions from Andes to the Himalayas are warming at faster rate than global average. Global warming is likely to have significant impact on the hydrologic cycle and some of the most important and immediate effects are change in local/regional water availability, frequency and intensity of flood/droughts, and rainfall patterns.

## 2.2 Methodology and Indicators

The key input variables that affect the water resources from the Himalayas include :

- Precipitation from rainfall and snowfall, glaciated area in the region and its contribution to the water resources,
- Glacial lakes and their status, hydro-meteorological variables (particularly temp.) which affect the nature of precipitation and melting of snow and glaciers, quantum of virgin river flows generated from rainfall
- Snow/glacier-melt along with its spatial and temporal distribution, quantum of virgin sediment flow generated from rainfall and snow/glacier-melt processes along with its spatial and temporal distribution, and the quality of generated flows in rivers.

To evaluate the health of Himalayas in hydrological terms, it is important to assess the long-term trend of variables mentioned above.

The precipitation and hydro-meteorological variables are being measured by the India Meteorological Department (IMD) since long time (since the year 1901 though the data series length varies for different stations) and their data can be utilized to evaluate the trend of hydro-meteorological variables. In addition, available hydro-meteorological data of Central Water Commission (CWC) and various agencies in the Himalayan States can also be utilized for this purpose. In addition, Snow and Avalanche Study Establishment (SASE) have observations of hydro-meteorological variables through their AWS which can be utilized for the purpose. Further, National Institute of Hydrology (NIH) and WADIA Institutes have established a few observatories under different projects and their data can also be utilized for the purpose.

The information related to snow cover area and its extent in different elevation bands, including its temporal variation, can be obtained from the different satellites with different spatial and temporal resolution. One such scene of MODIS satellite with the overlaid Himalayan States is shown in Figure 2.1. We-GIS applications have also been developed in this regard which show the derived snow cover information for different dates in the Himalayan States as shown in Figure 2.2.

Information related to the glaciers and glacial lakes and changes in glacial area over recent past can be obtained from the inventories prepared by the GSI and the ISA-ISRO. Further, latest changes in glacier areas and glacial lakes can also be obtained from the processing of satellite data.

Long-term river flow and sediment data are measured by the CWC. In addition, there are some State agencies which maintain flow observation stations at some locations. However, in view of the continuity of data of CWC for long-term observations, it is preferable to use the data of CWC for river flow and sediment record. It needs to be mentioned that the observed flow data is not virgin as there may be abstractions by the upstream utilizations (domestic, industry, irrigation etc.) or flow obstruction by the upstream projects. To find trend of river flows and sediments, it is important to find flows corresponding to virgin conditions.

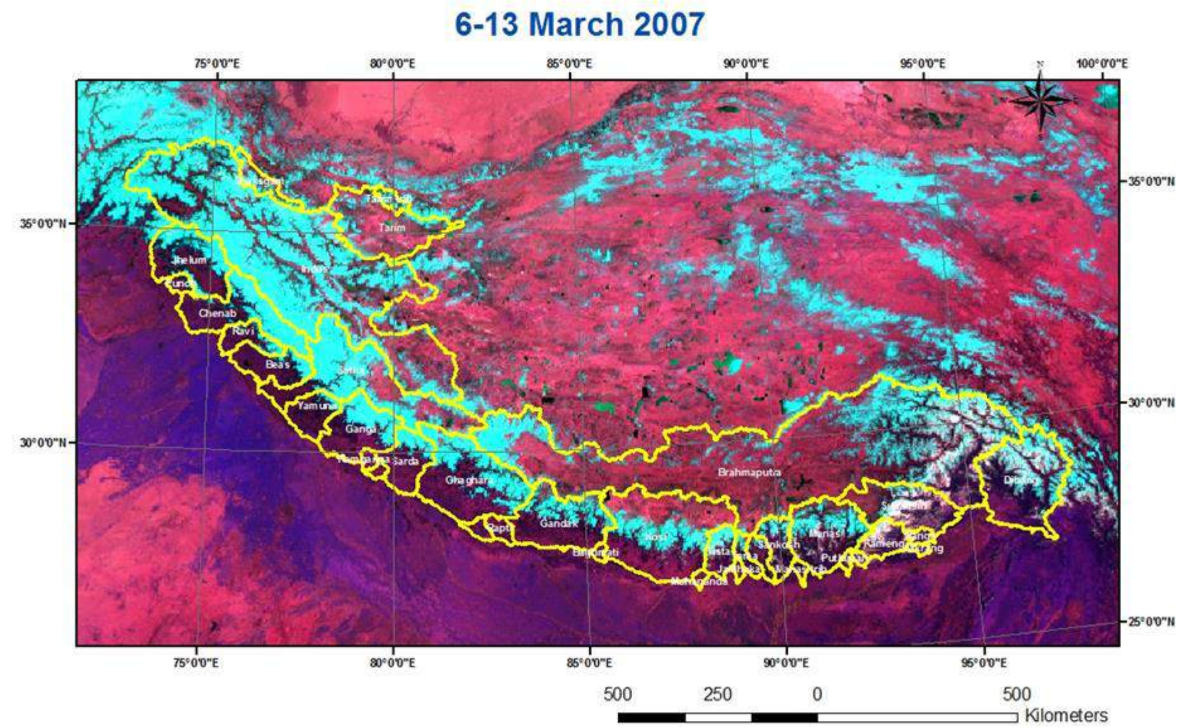


**Figure 2.1. Himalayan winter snow cover as seen from MODIS satellite**

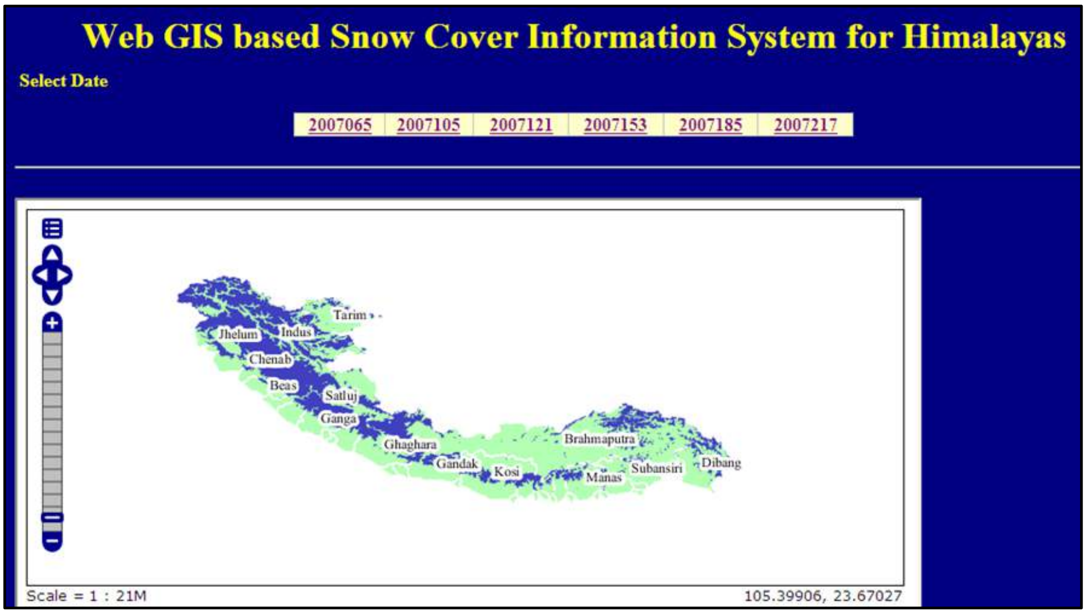


**Figure 2.2. Web-GIS based snow cover information for Himalayas**

In view of the water related data and their sources, a few indicators have been identified to judge the status of health of the Himalayan region as given below:

a) Trend of precipitation and its spatial distribution in different time scales (monthly, seasonal, annual)

b) Trend of meteorological variables, especially temperature, and its spatial distribution in different time scales (monthly, seasonal, annual)
c) Snow cover area and its spatial and temporal distribution
d) Characteristics of glaciers and glacial lakes (area, mass balance etc.) and their advancement/retreat
e) River flow in the region and its spatial and temporal distribution
f) Sediment flow in the region and its spatial and temporal distribution
g) Quality of surface and groundwater

## 2.3 Status & Trends of the Water-related Indicators of Himalayan health

Some of the trends for the specified indicators are discussed below.

### *2.3.1 Precipitation*

A number of studies have been carried out to estimate the trend of precipitation in different river basins in the Himalayas. Different length of available data series has been used for different stations. A few figures are illustrated here to show the long-term trends. Most of these figures are self-explanatory showing the name of the station and the period of record used in the estimation of the trend.

For the Kashmir region in general, the annual precipitation and number of rainy days show a decreasing trend, though the rate of decrease vary considerably for different stations. As can be observed, some exception to these trends have also been observed if the period of observation is slightly shifted as is the case of precipitation trends at Srinagar station.

There are around 14 precipitation stations in Chenab basin and therefore, they have been clubbed in different groups to get regional trend. All the groups in Figure 2.5 show increasing precipitation trend in the basin as seen from the observations from 1975 to 2000.

In the Satluj basin, spatial variation of z-statistics of the trend analysis of precipitation plotted has been given in Figure 2.6. Z-statistics shows the confidence in establishing the trend of a variable in a particular region. Values with 1.96 indicates the increasing (+) or decreasing (-) trend with 95% confidence. More is the z-statistics, higher is the degree of confidence. Generally, values lesser than 1.96 are not assumed to signify any established trend in a variable. Thus most of the region in Satluj basin (except for area close to Rakcham) shows any established trend in precipitation.

Similarly, the trends of annual and seasonal rainfall at various stations in Uttarakhand region have been estimated by Singh and Mal (2014) can be seen in Figure 2.7. Trend values with <95% confidence level have been treated to have statistically insignificant trend. Figure indicates the magnitudes of trends estimated using Sen's slope method. On the *x* axis, different seasons and year (aggregate of all seasons) have been shown through bars, while the *y* axis indicates trends values (mm per year). 1 cm on the vertical *y* axis indicates 9 mm/year of trend magnitude

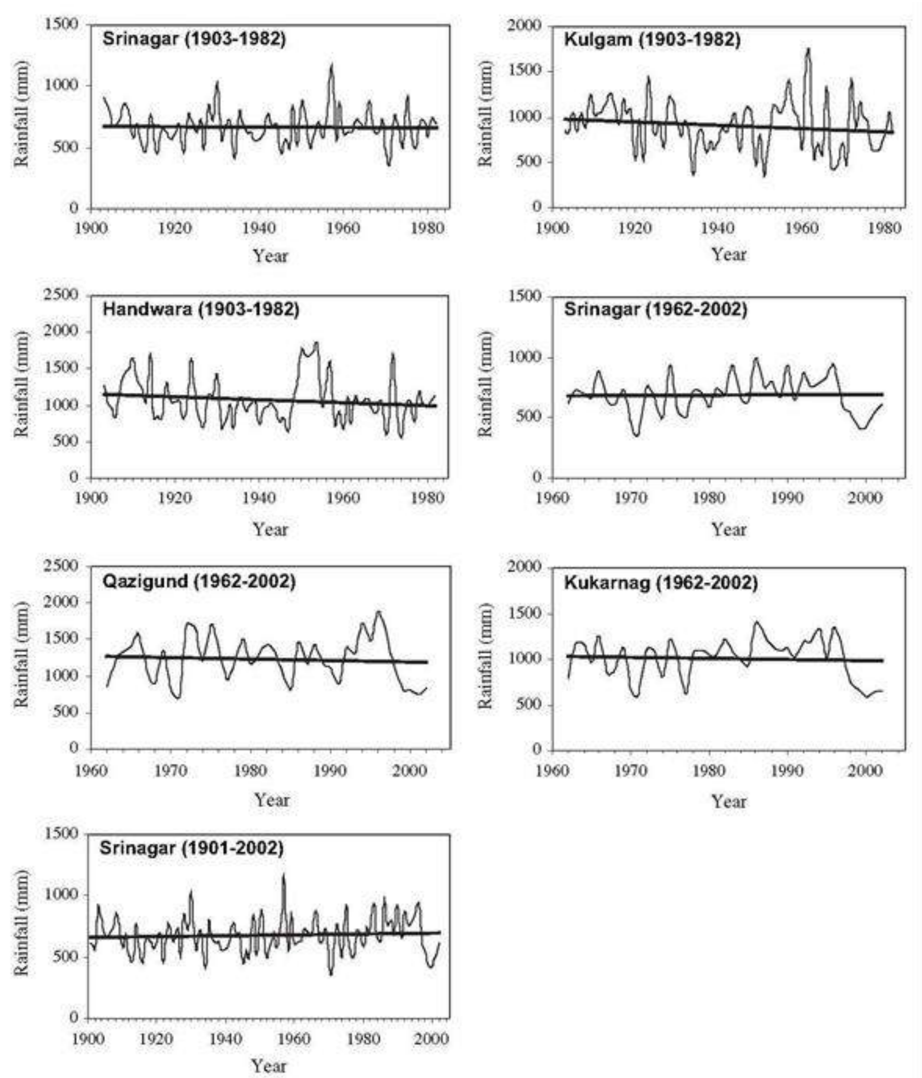


**Figure 2.3. Linear trend in annual rainfall at different stations in Kashmir Valley**

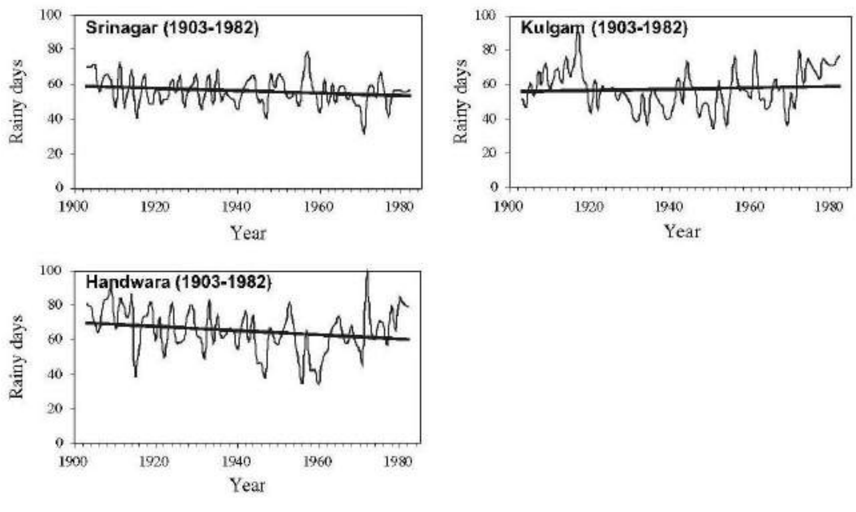


**Figure 2.4. Annual rainy days at different stations in Kashmir Valley**

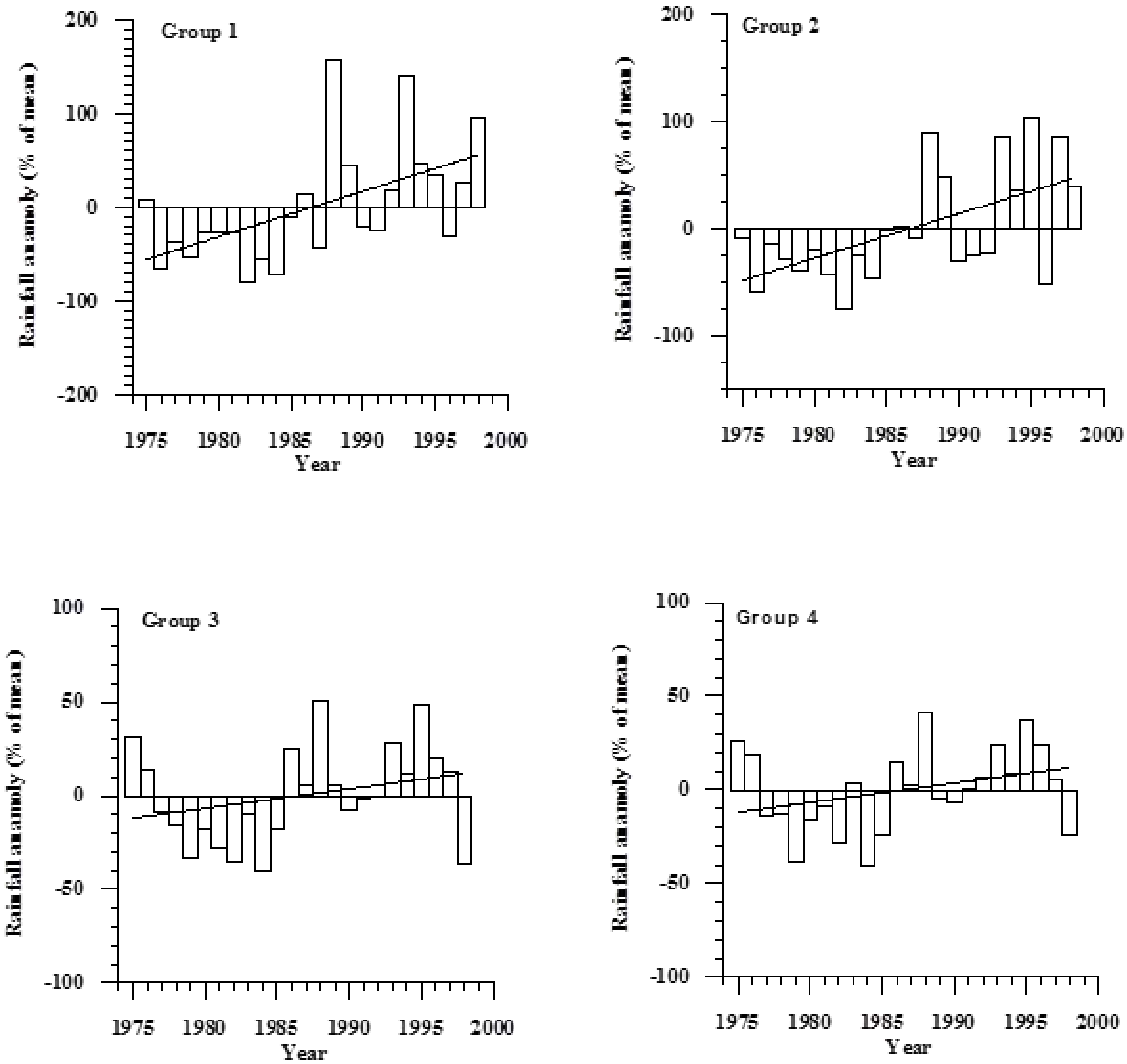


**Figure 2.5. Trends of annual rainfall at different stations in Chenab basin**

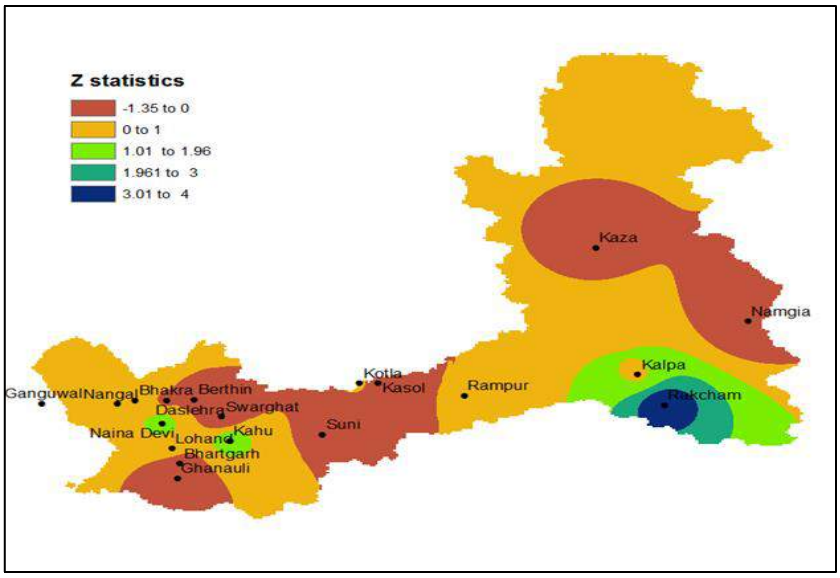


**Figure 2.6. z-statistics of trends analysis of annual precipitation in Chenab basin**

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**Figure 2.7. Trends of precipitation in Uttarakhand State using Sen's Slope method**

Trend analysis of the precipitation of Uttarkashi has been carried out with the observed data from Central Water Commission (CWC) in Upper Ganga basin under NMSHE-NIH project. The data has been analysed for the period from 1972 to 2018. The annual rainfall is found to vary between 948.40 mm (1998) to 3367.40 mm (2011) with the average rainfall as 1936.71 mm. Mann-Kendall's trend analysis was carried out on the annual rainfall series, which showed a significant rising trend in annual rainfall (z-value = 2.708) at 5 % significance level.

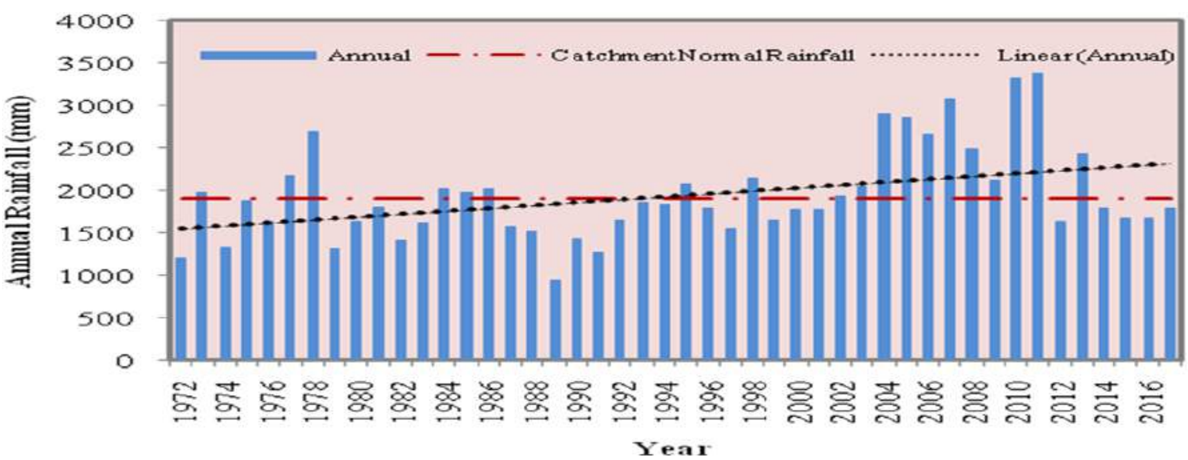


**Figure 2.8. Variation of annual rainfall at Uttarkashi**

The monthly rainfall plot shows that July month receives highest rainfall followed by August while the November month receives minimum rainfall. Around 79% of rainfall (around 1502 mm) is received during five monsoon months (June to October).

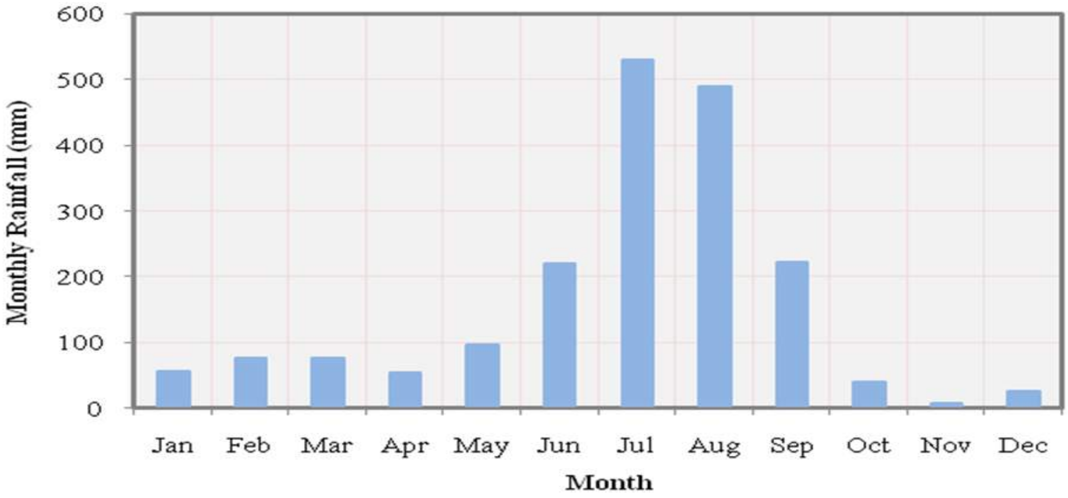


**Figure 2.9. Variation of monthly rainfall at Uttarkashi**

Mann-Kendall trend analysis was also carried-out on seasonal basis at 5% significance level and the analysis indicates the following:

- During summer (March to May) season, rainfall is increasing but the increase is not-significant (z-value = 1.155).
- During monsoon (June to September) season, rainfall is increasing and the increase is significant (z-value = 2.556).
- During winter (October to February) season, rainfall is decreasing but the decrease is not-significant (z-value = -0.739)

A pan-Himalayan view depicting the widespread trends of seasonal and annual precipitation (mm per year) in different eco-regions of the Himalayas has been prepared by Shrestha *et al*. (2012) which is depicted in Figure 2.10.

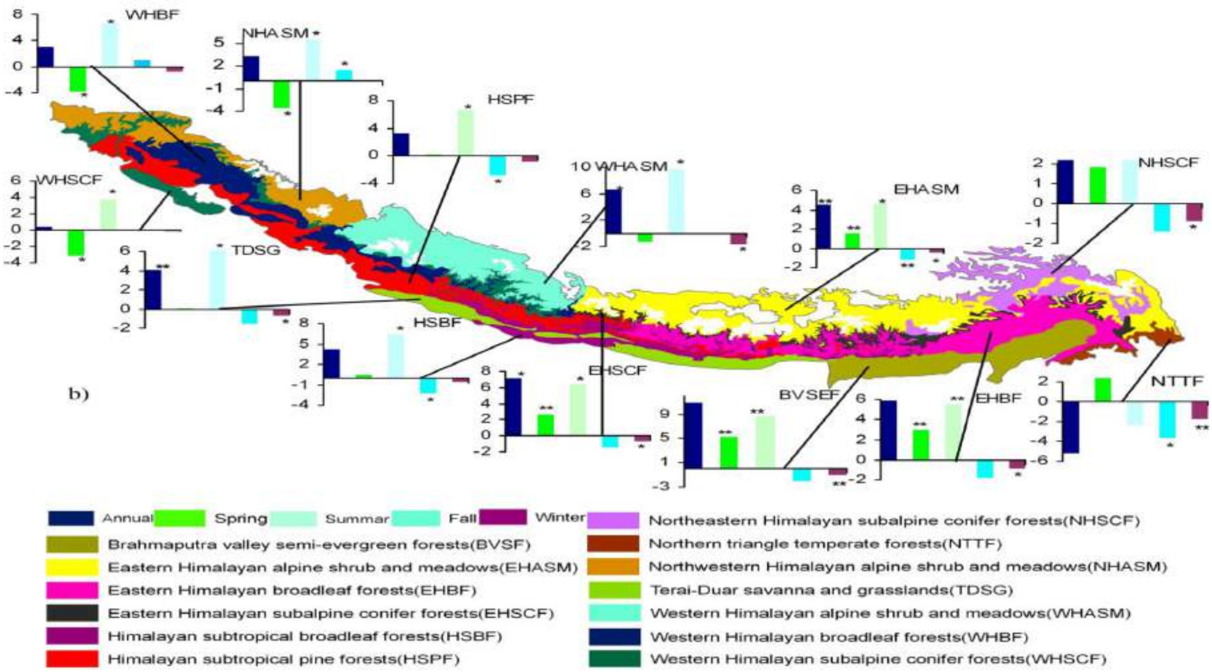


**Figure 2.10. Widespread analysis of precipitation trend in the Himalayas**

### *2.3.2 Temperature*

In addition to the precipitation, trends in temperature variation from the past records have also been estimated in different studies for different regions. Some of the salient aspects for different river basins are presented below.

Figure 2.11 shows the grid-averaged trends in the annual mean temperature in the Hindu-Kush Himalayan region over more than last 100 years (1901 – 2014). The box colours indicate the station number and white grid boxes indicate missing data. It is seen that increasing temperature trend is clearly visible, though with different magnitude, in different regions.

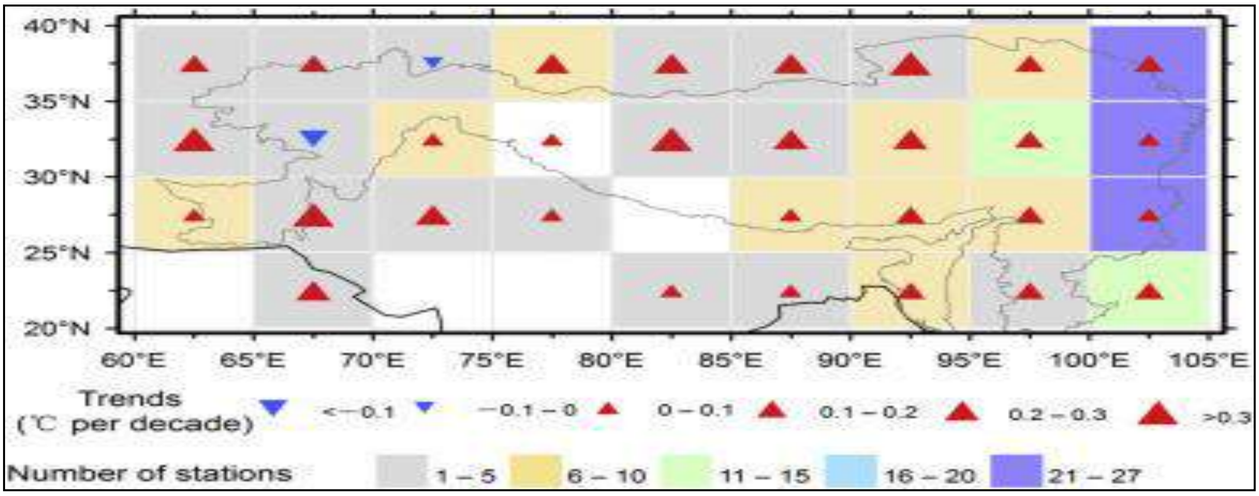


**Figure 2.11. Grid-averaged trends of annual mean temperature in HKH region**

The z-statistics of the temperature trend in the Satluj basin is plotted in Figure 2.12. This shows warming trend in the south-east part of the basin only.

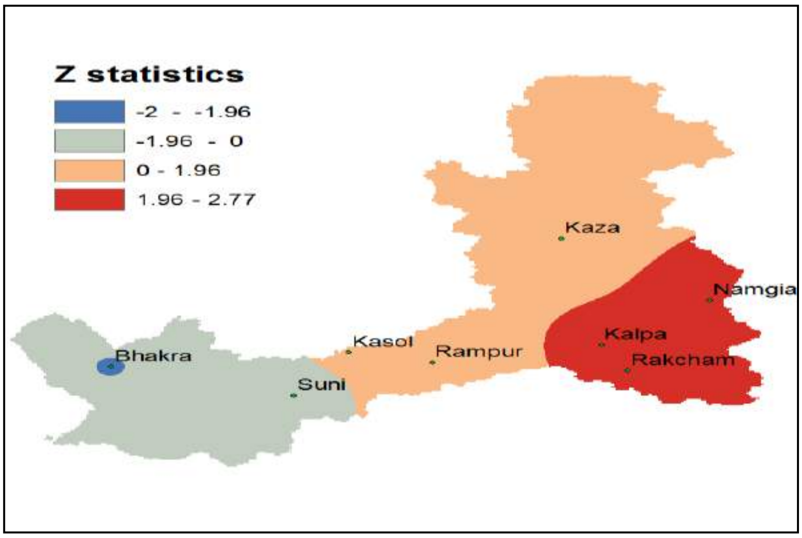


**Figure 2.12. Spatial trends of temperature in the Satluj river basin**

Similarly, the variation of temperature during 1975–1990 at Sirshi in the Chenab basin shows a rising trend as shown in Figure 2.13.

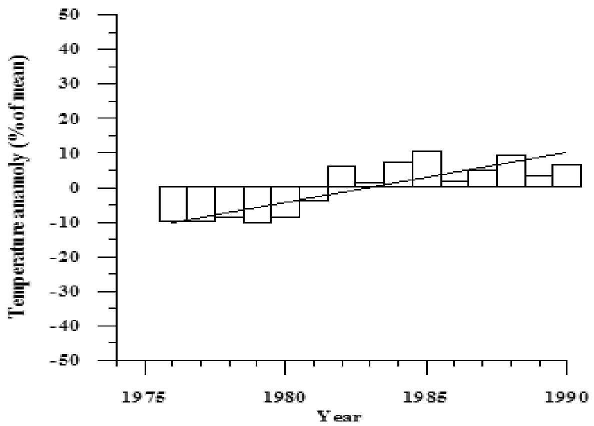


**Figure 2.13. Mean annual temperature variation at Sirshi in the Chenab river basin**

Trend analysis of the temperature has been carried out with the observed data (1972 – 2018) from Central Water Commission (CWC) in Upper Ganga basin under NMSHE-NIH project. For the Uttarkashi region, it is found that peak summer occurs during 20th May to 30th June and the average temperature during the monsoon period (June to September) is more than the summer period (March to May).

Mann-Kendall's trend analysis was carried out on the minimum, mean and maximum temperature series at 5% significance level. Minimum temperature showed significant declining temperature trend (z-value = -2.103) while mean temperature showed not-significant (z-value = -0.518) decreasing trend and the maximum temperature showed not-significant (z-value = 1.105) rising temperature trend.

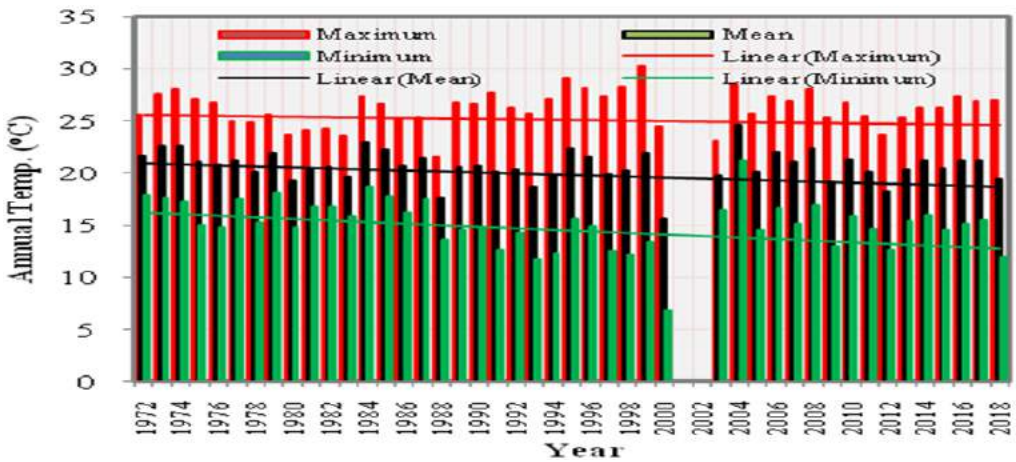


**Figure 2.14. Variation of annual temperatures at Uttarkashi**

Mann-Kendall trend analysis is also carried-out for temperature data at Uttarkashi on seasonal basis at 5% significance level. The analysis indicates the following:

*Minimum Temperature:*

- During all three seasons [summer (March – May), monsoon (June – Sept), and winter (October – February)], minimum temperature is decreasing but not-significantly (z-value = -1.831, -1.319, and -1.008)

- On annual basis, minimum temperature is decreasing significantly (z-value = -2.103)

*Mean Temperature:*

- During summer season, mean temperature is decreasing but not-significantly (z-value = -0.142).
- During monsoon season, mean temperature is decreasing but not-significantly (z-value = -1.402).
- During winter season, mean temperature is increasing but not-significantly (z-value = 1.673).
- On annual basis, mean temperature is decreasing but not-significantly (z-value = -0.518).

*Maximum Temperature:*

- During summer season, maximum temperature is increasing but not-significantly (z-value = 0.273).
- During monsoon season, maximum temperature is decreasing but not-significantly (z-value = -1.298).
- During winter season, maximum temperature is increasing significantly (z-value = 2.123).
- On annual basis, maximum temperature is increasing but not-significantly (z-value = 1.105).

A pan-Himalayan view depicting the widespread trends of seasonal and annual temperature (degree C per year) in different eco-regions of the Himalayas has been prepared by Shrestha *et al.* (2012) which is depicted in Figure 2.15.

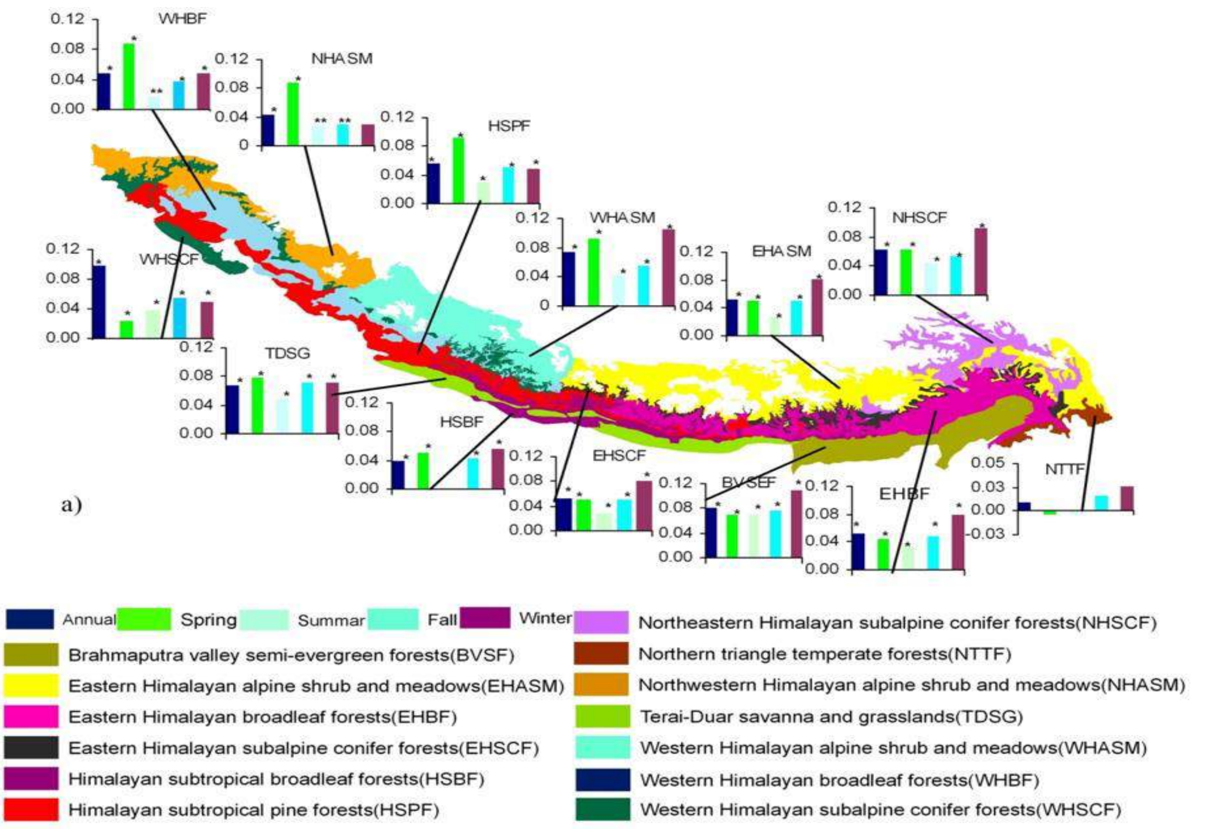


**Figure2.15. Widespread analysis of temperature trend in the Himalayas**

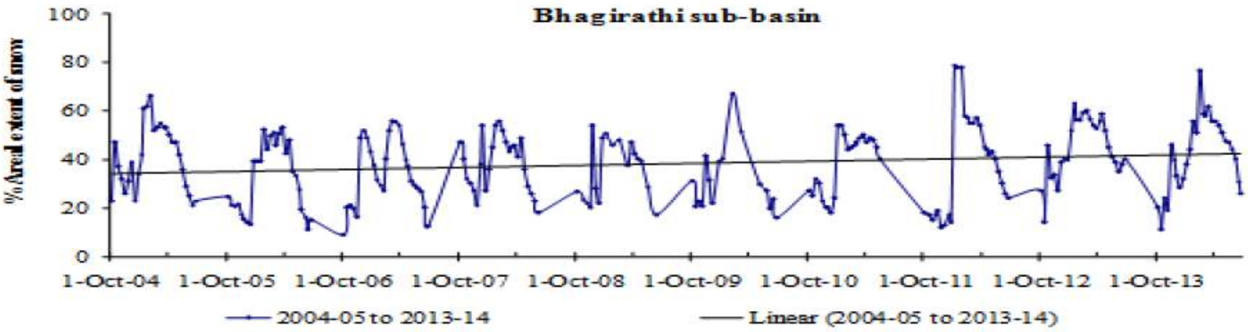


**Figure 2. 16. Increasing trend of SCA in Bhagirathi basin 2004-14 using AWiFS (SAC 2016)**

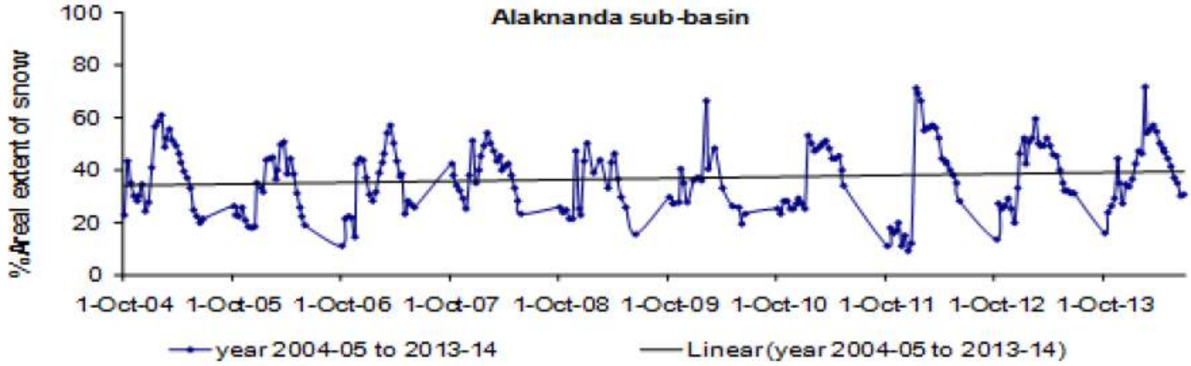


**Figure 2. 17. Consistent trend of SCA in Alaknanda basin 2004-14 using AWiFS (SAC 2016)**

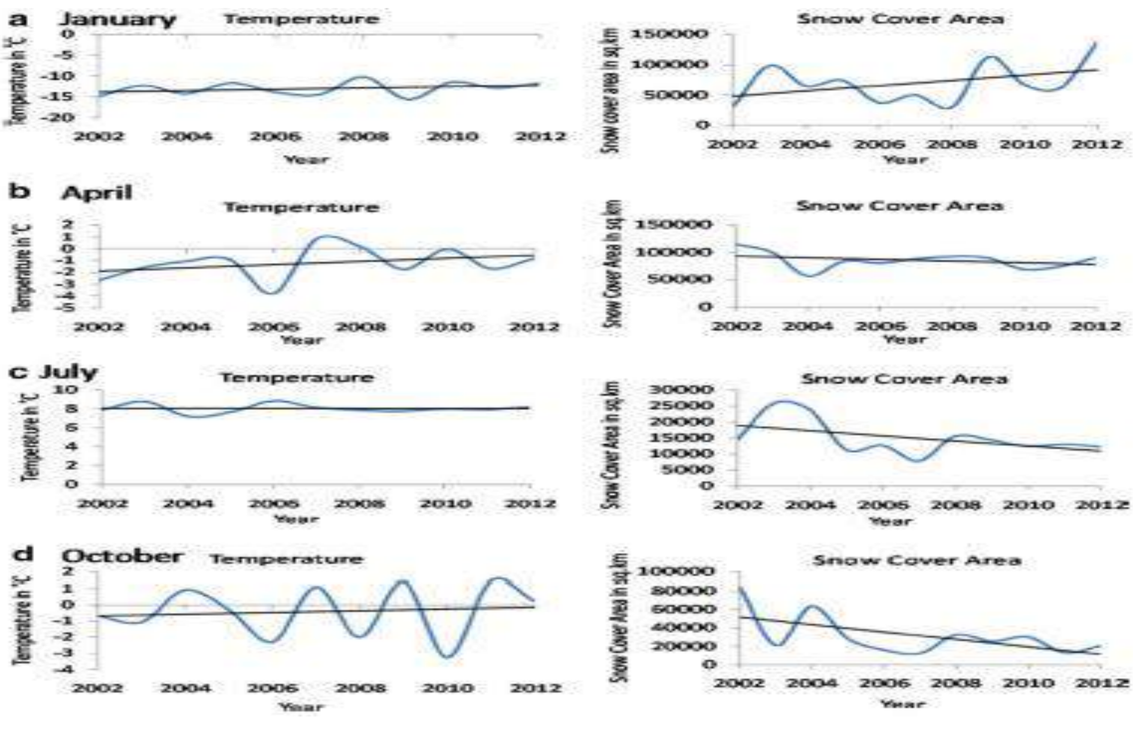


**Figure 2.18. Trend of temp. & SCA in Brahmaputra basin (Barman & Bhattacharjya 2015)**

Yearly median snow cover extent in Upper Ganga basin for February-March and April-May have been derived in the NMSHE-NIH project from post-processed and gap-filled NSIDC eight-day MODIS snow extent data which indicate no specific trend at 95% significance level. The results are briefly illustrated in Figures 2.19 and 2.20 respectively.

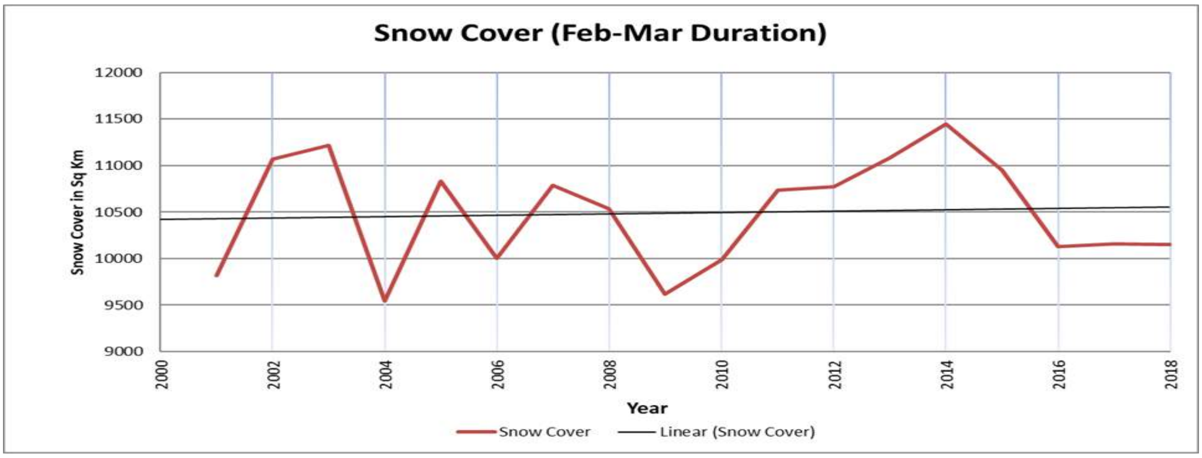


**Figure 2.19. Yearly median snow cover for Feb-March from MODIS data for UGB**

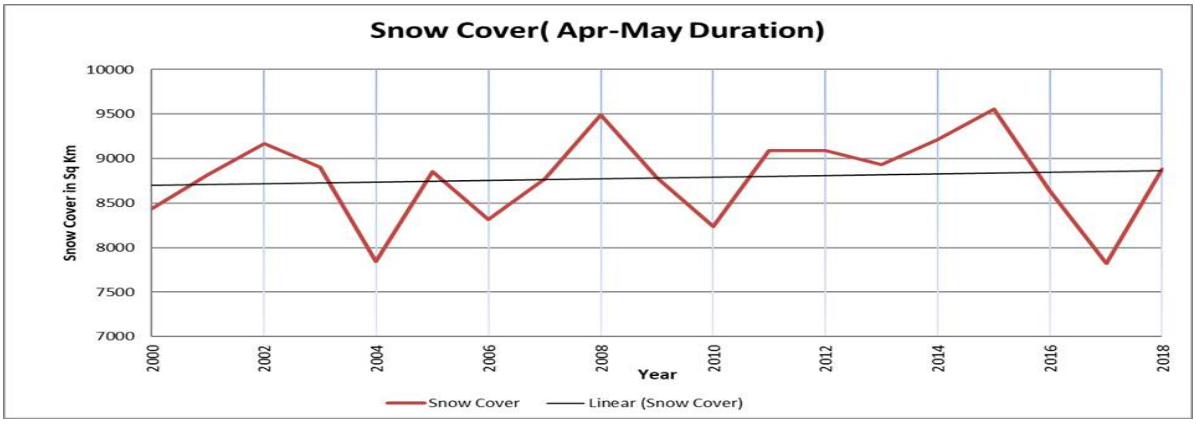


**Figure 2.20. Yearly median snow cover for March-April from MODIS data for UGB**

### *2.3.4 River flows*

The flows in the rivers in Himalayan region are an integrated effect of precipitation, temperature, and snow and glacier melt. Though the abstractions of river flows for different utilizations affect their availability in the downstream regions, the quantity of abstractions keeps on decreasing with elevation because of lesser population and other developmental activities. Further, these abstractions may be of constant nature at annual time step and may not be quantitatively significant in comparison to river flows. Therefore in most of the cases, the trends of observed flows have been estimated at selected sites rather than trends of computed virgin flows which is a tedious exercise because of non-availability of temporal utilization statistics. The trends of river flows as predicted in a few studies are depicted below (Figure 2.21 – 2.23).

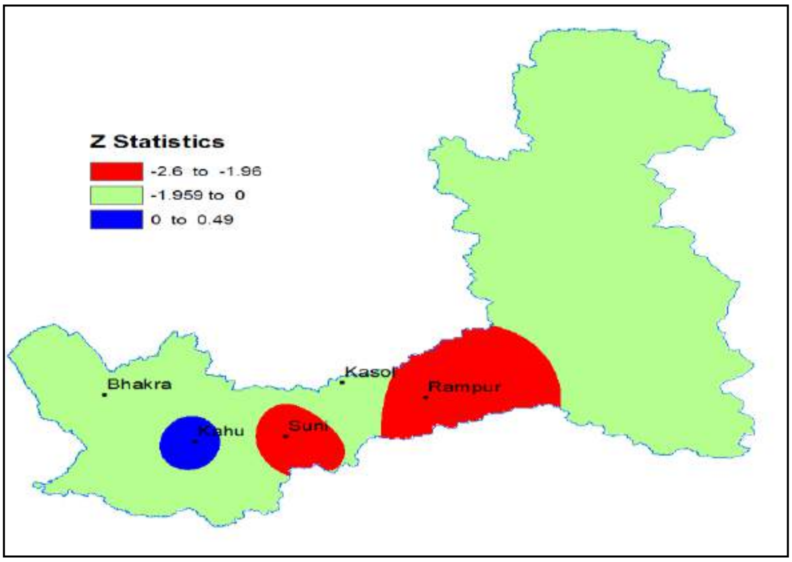


**Figure 2.21. Trends in annual flow in Satluj basin**

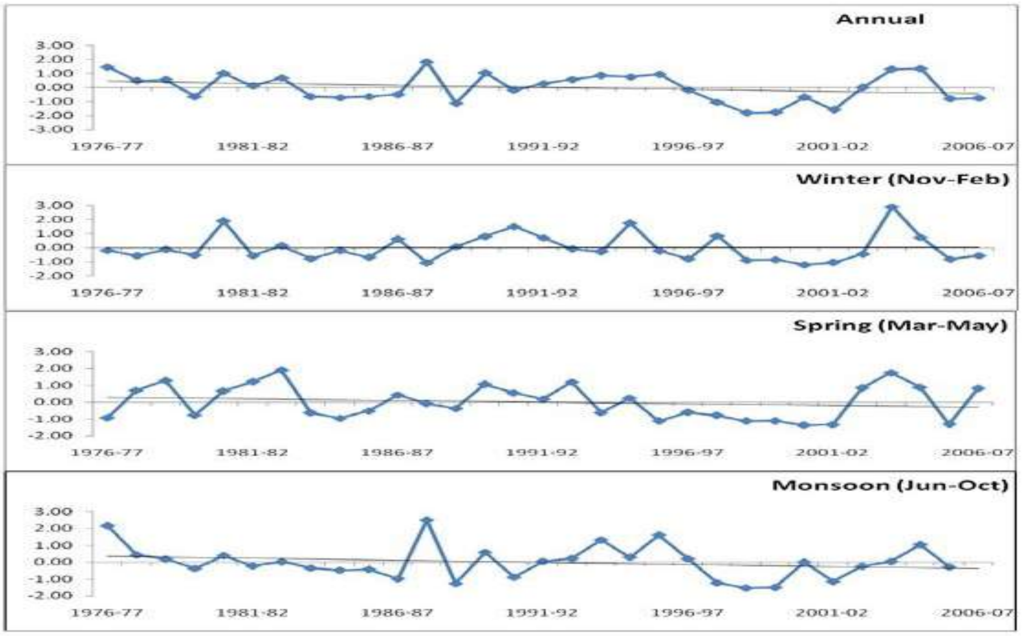


**Figure 2.22. Trends in seasonal/annual flow in Tawi river at Jammu**

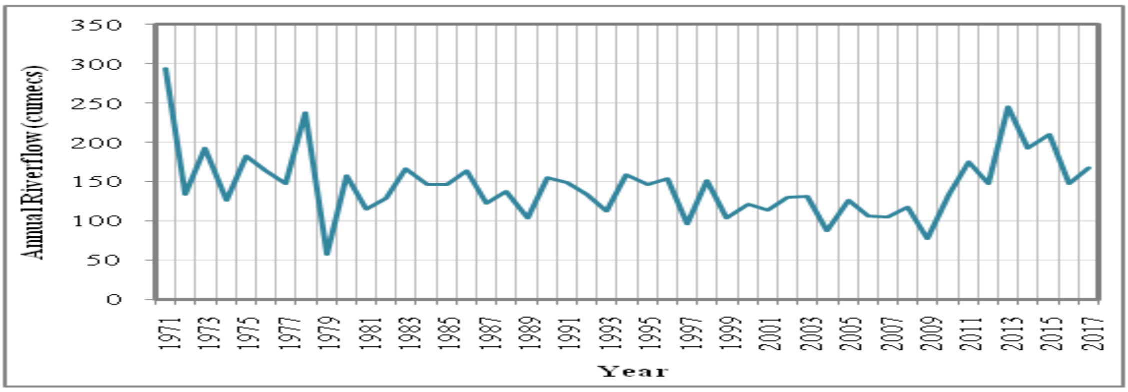


**Figure 2.23. Variation of annual river flows at Uttarkashi**

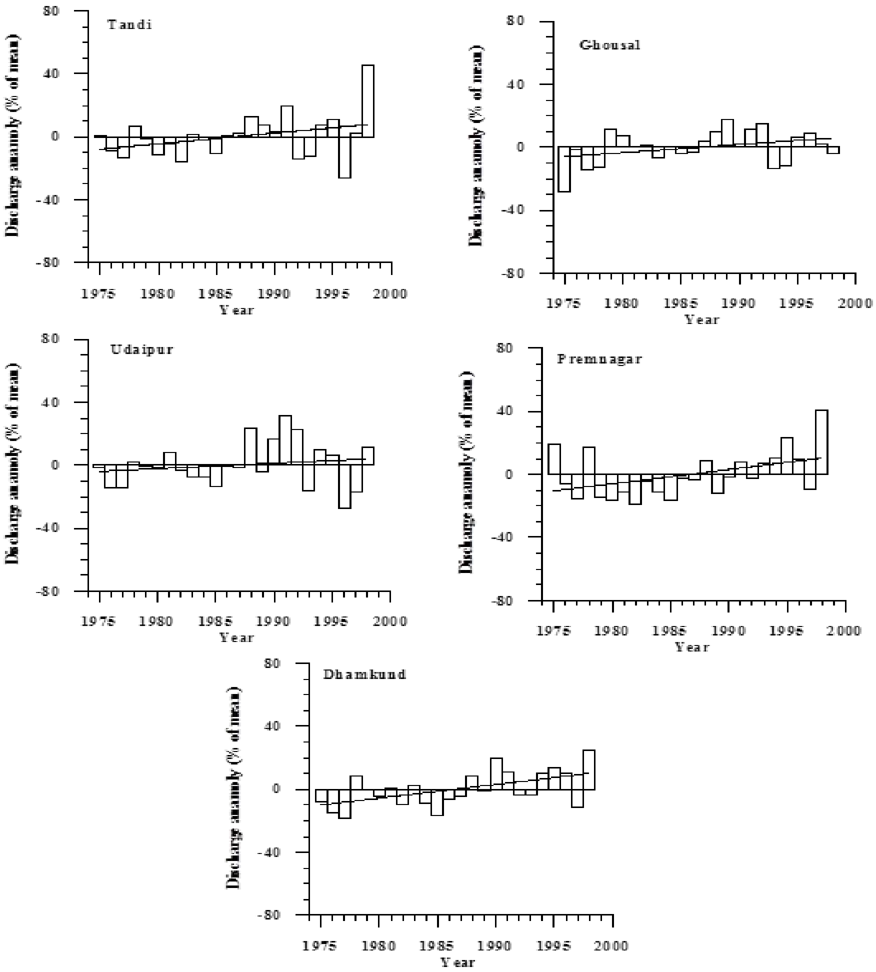


**Figure 2.24. Trends in annual flow at various stations in Chenab basin**

To carry out the trend analysis on the river flows under NMSHE-NIH project, observed data of Central Water Commission (CWC) at Uttarkashi gauging station (July 1971 to June 2018) have been used. The annual river flow varies between 57.59 cumec (1979) to 293.35 cumec (1971) with average flow as 144.93 cumec.

The Mann-Kendall's trend analysis was also carried out on the summer, monsoon, winter and annual riverflow series which indicate that:

- During summer season (March – May), river flow is decreasing significantly (z-value = -2.054).
- During monsoon season (June – Sept), river flow is decreasing though not-significantly (z-value = -0.147).
- During winter season (October – February), river flow is decreasing significantly (z-value = -3.430).
- On annual basis, riverflow is decreasing though not-significantly (z-value = -1.009).

NIH has established an observatory near the snout of the Gangotri glacier since the year 2000. The Gangotri Glacier is a valley type glacier system with total glacierized area of about 286 $km^2$. Total catchment area of the Gangotri Glacier (elevation range from 4000 to 7000

m) and melt stream up to the discharge-gauging site of NIH is about 556 km$^2$.The Gangotri Glacier system (shown in Figure 2.19) most commonly known as Gangotri Glacier, is a cluster of many glaciers comprising of main Gangotri Glacier (86 km$^2$) as trunk part of the system with major glacier tributaries as Raktvarn Glacier (55.30 km$^2$), Chaturangi Glacier (67.70 km$^2$), Kirti Glacier (33.14 km$^2$), Swachand Glacier (16.71 km$^2$), Ghanohim Glacier (12.97 km$^2$), Meru Glacier (6.11 km$^2$), Maindi Glacier (4.76 km$^2$) and few others having glacierized area of about 3.08 km$^2$. Dataset at the observatory includes rainfall, temperature, humidity, wind speed and direction, sunshine hours, radiation, evaporation, discharge and suspended sediment. An AWS has been installed at Bhojwasa site.

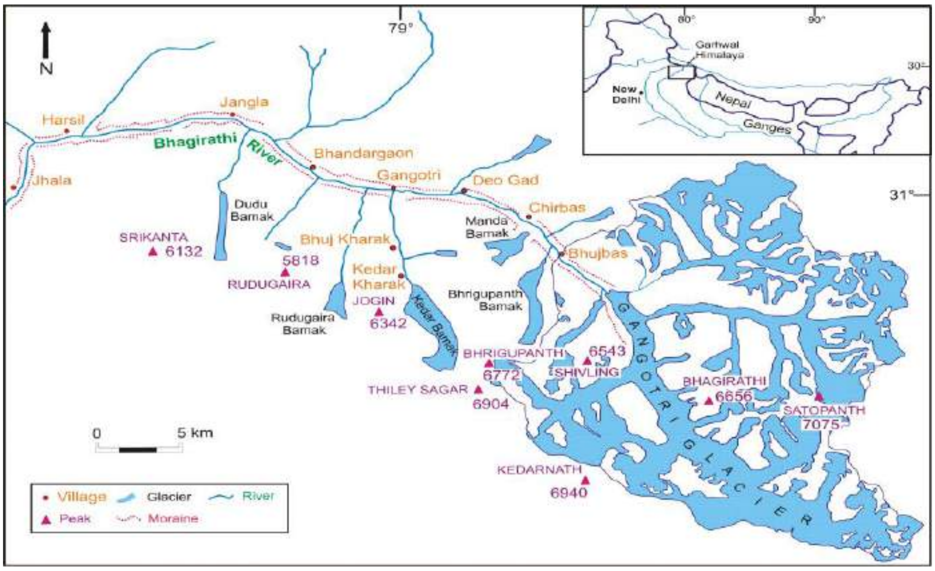


**Figure 2.25. A view of the Gangotri glacier system**

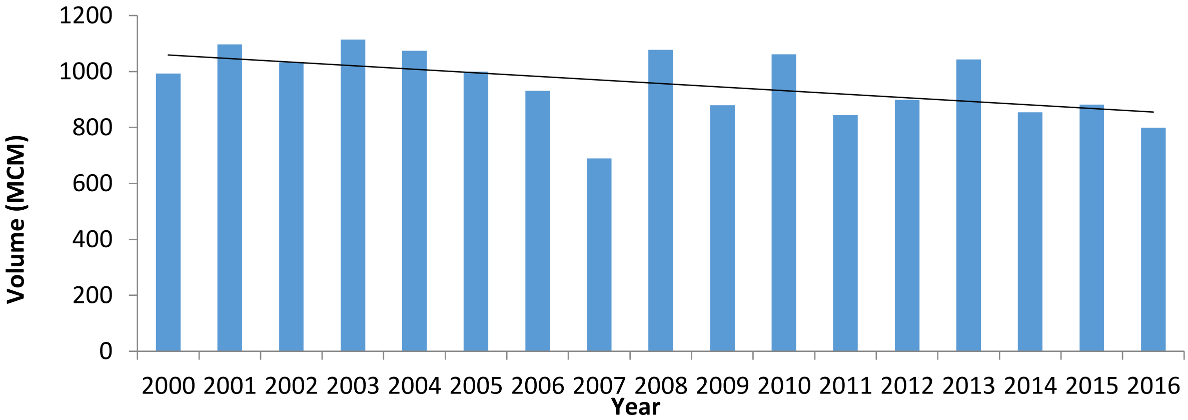


**Figure 2.26. Trends in seasonal flow (May–October) at Bhojwasa gauging site of NIH**

Some salient hydro-meteorological observations at the site include: mean temperature (May to October): 9.11ºC, mean seasonal rainfall: 260 mm, mean pan evaporation: 598 mm, and mean daily sunshine hours: 5.5 hours. Total seasonal volume of water during 2000 to 2016 has been observed to vary from 680 to 1114 MCM. The individual concentration in stream flow from snow/glacier melt, rainfall and sub surface flow is found to be 85%, 3% and 12% respectively. The distribution of observed runoff indicates maximum runoff in July (33.39%) followed by August (29.46%). The strong storage characteristics of the Gangotri Glacier are reflected by the comparable magnitude of runoff observed during daytime and night time. Daily mean concentration of suspended sediments varies between 34 to 11093 ppm. The plot of flow observations for the 16 years of record signifies a decreasing trend as shown in Figure 2.26.

### *2.3.5 Glaciers and glacial lakes*

In the Hindu-Kush-Himalayan (HKH) region, approximately 40,800 km$^2$ area is covered by the glaciers (Bolch et al., 2012) varying in shape and size with a total number of 9,600 glaciers in the Indian Himalaya (Raina and Srivastava, 2008). The Himalayan glaciers are created in single or compound cirque basins ranging from 0.5-143 km$^2$ in area (Raina and Srivastava, 2008). Moreover, a large number of glaciers, classified as compound valley type glaciers, are formed by the convergence of two or more tributary glaciers (Mullar et al., 1977; Raina and Srivastava, 2008). However, the shrinkage of these glaciers is being discussed extensively, as it can affect the supply of water to a large number of people dependent on waters of these rivers.

During recent past, numerous investigations have been carried out to understand the loss in its area and estimates for almost 6000 glaciers covering an aerial extent of 20,000 km$^2$ are available. Generally, these glaciers are losing at an average rate of 0.4% of area per year (Bolch et al., 2012; Yong et al., 2010; Kamp et al., 2011; Bhambri et al., 2011; Kulkarni et al., 2011). During the last four decades, the monitoring of snout positions of a number of glaciers has been under investigation for several glaciers in different parts of the Indian Himalaya (Bhambri and Bolch, 2009). Furthermore, it is suggested that the fragmentation of tributary glaciers from the main trunk may also be a consequence of rapid recession. Additionally, an increased receding trend has been exhibited by Himalayan glaciers (Chaujar, 2009; Mehta et al., 2011) during recent decade. Therefore, the impact of climate change on glaciers is quite obvious and already occurring in the Himalayan region (Bhutiyani, 1999; Bhutiyani et al., 2008; Hasnain, 2008; Bhambri et al., 2011). The most widely reported manifestation of impact is the rapid recession of glaciers with its implications for future downstream water supplies (Yao et al., 2004; Barnett et al., 2005; IPCC, 2007; Nogues-Bravo et al., 2007; Krishna, 2005; Rees and Collins, 2006; Kehrwald et al., 2008). Further, the glacial lake outburst flood (GLOF) caused due to glacier retreat have often catastrophic effects on the community and sustainable development down the stream. In addition, Himalayan glacier change is likely to contribute significantly to the sea-level change (Dyurgerov and Meier, 2005).

The climate change has caused a continuous glacier recession and the emergence of glacial lakes behind the newly exposed unstable moraines in most of the glaciated regions of the world (Kaser et al., 2006; Zemp et al., 2009; Bolch et al., 2012; Mir et al., 2015). Like other regions, the formation of glacial lakes in the Himalayas in response to climate change is a new development and most of the lakes in this region have formed within the last 50 years (Raj, 2010). Majority of these lakes are behind loosely consolidated end-moraine dams typically composed of poorly consolidated glacial material. During recent past, a number of glacial lakes have been identified and found expanding in response to climate change and glacier thinning (Reynolds, 2000; Ageta et al., 2000; Benn et al., 2000). The moraines provide a physical barrier to glacial melt water drainage resulting in the creation of a moraine-dammed glacial lakes (Costa and Schuster, 1988) with a potential for a glacial lake outburst flood (GLOF) hazard (Benn et al., 2012; Westoby et al., 2014; Worni et al., 2014).

Normally, two types of glacial lakes are recognized such as (i) pro-glacial lakes and (ii) supra-glacial lakes. The pro-glacial lakes often grow downstream of steep glaciers, where water is collected behind former moraines (Richardson and Reynolds, 2000a; Komori, 2008) due to recession of the glacier terminus (Frey et al., 2010; Westoby et al., 2014) whereas, the supra-glacial lakes develop on the surface of glacier itself and grow by coalescence of small ponds (Richardson and Reynolds, 2000a; Benn et al., 2001, 2012; Thompson et al., 2012). These glacial lakes have the capacity to impound large volumes of melt following the continuous lake expansion (Sakai et al., 2000; Janský et al., 2009; Somos-Valenzuela et al., 2014). Due to the impoundment of huge volumes of water and unstable nature of moraine deposits, such lakes have high tendency of breaching and therefore could be dangerous. In case of any breaching, the resulting rapid discharge/burst of massive amounts of water and debris is known as a glacial lake outburst flood (GLOF). Such a GLOF can be catastrophic in downstream areas in mountainous regions (Richardson and Reynolds, 2000a). Considering this, the glacial lakes should be monitored regularly, so that mitigation measures could be taken in time.

A first step for the assessment of GLOF hazards is the identification of potentially dangerous glacial lakes (PDGLs). However, this is difficult, cumbersome and time-consuming by conventional methods due to inaccessibility and harsh weather conditions prevailing at high-altitude region such as Himalayas. Therefore, the techniques of GIS and remote sensing are highly suitable as such techniques permit rapid analysis of large areas and number in an inexpensive way (Huggel et al., 2002; Kääb et al., 2005). Using such techniques, the vulnerable lakes can be easily identified and detailed studies (e.g., GLOF modeling) can be carried out if found prone to pose any potential risk to communities or infrastructure located in the downstream of the lake (Bajracharya et al., 2007; Mergili and Schneider, 2011; Worni et al., 2012). It is pertinent to mention that the modeling of GLOF is usually similar to the dam break study of the moraine dams (Jain et al., 2012, 2015). Generally, the scaled physical hydraulic models or mathematical simulation models are frequently used for the dam break flood simulation studies (WECS, 1987; Carrivick, 2006; Bajracharya et al., 2007).

In the Himalayas, the risks to human life and property located downstream of PDGLs have increased due to the more frequent glacier recession. The first GLOF event in the Indian Himalaya has been reported in 1926 in which a flood was released from the Shyok glacier, Jammu and Kashmir destroying the Abudan village and the surrounding land at a distance of 400 km from the outburst source (Mason, 1929). Sangewar et al., (1999) has also reported sudden emptying of some of the moraine dammed lakes of Shaune Garang glacier in the Indian Himalayas based on high discharge measurements downstream during 1981 to 1988. During June, 2005 an outburst of landslide dammed lake at Parechu River (China) caused a transboundary flood in Himachal Pradesh, India. Chorabari Lake in Kedarnath was very disastrous event in the year 2013. As reported, the Himalayas have 9000 glacial lakes created from 15,000 glaciers (Bajracharya et al., 2006; ICIMOD, 2011). In an attempt, Worni et al., (2012) has provided an inventory of 103 glacial lakes for Indian Himalayan region.

Glacier change studies have been carried out at NIH in two sub-basins of Satluj basin. A glacier inventory has been prepared using Survey of India (SOI) topographical maps (1966) and Landsat datasets as ETM+ (2000, 2006) and TM (2011) to study glacier changes in Tirungkhad basin. This basin a part of Satluj basin is located in western Himalaya. Glacier areal changes showed a deglaciation of 26.1% (29.1 $km^2$) from 1966 to 2011. Smaller glaciers (area <1 $km^2$) lost more ice (34%), while glaciers with (area >10 $km^2$) lost (20%). Glacier volume loss was found to be 32.0% (2.9 $km^3$) from 1966 to 2011. The north facing and low altitude glaciers showed high percentage of loss. A trend analysis of temperature, rainfall and snow water equivalent (SWE) has been carried out. During a period of 24 years (1984 to 2008), the mean annual maximum temperature has increased by 1.1ºC and minimum temperature has increased by 1ºC respectively, whereas snowpack and rainfall has decreased. SWE data from Purbani meteorological station within the basin also showed a decreasing trend. This observation indicated that the warming of the climate is probably one of the reasons for the glacier retreat in the basin.

Using the Landsat data (MSS, ETM+ and TM), the changes in glacier area, length and debris cover have been delineated in the Baspa basin, which is a highly glacierised sub-basin of Satluj River in the western Himalaya. Out of the total 109 glaciers inventoried through Landsat TM image (2011), 36 glaciers were found to be heavily debris covered (32.5±1.6%). A shrinkage in glacier area of 41.2±6.1 $km^2$ (i.e., 18.1±2.6%) at a rate of 1.18±0.17 $km^2a^{-1}$ from 1976 (227.4±11.5 $km^2$) to 2011 (186.2±6.8 $km^2$) has been recorded. The overall glacier retreat studied for 33 glaciers varied from 3.3±0.03%, i.e. 0.87±0.06 km at a rate of 17.2±1 m $a^{-1}$ to 30±6.6%, i.e. 0.60±0.04 km at a rate of 24.8±0.2 m $a^{-1}$. Consequently, the debris cover has increased by 23.5±1.4 $km^2$ (16.3±7.1%) from 1976 to 2011. Overall, the clean, small sized, low altitude glaciers with south to southwest aspect and relatively steep slope have lost maximum area which indicated a major control of these factors on the glacier changes. Simultaneously, a trend estimation of observed climatic data (1985-2008) of 3 meteorological stations (Sangla, Rakcham and Chitkul) using Mann Kendall test, Sen's Slope estimator and Linear regression test revealed an increase in temperature and rainfall while a decline in snowfall. Importantly, the $T_{min}$ has increased significantly at 95% confidence level during all the studied periods. The mean annual $T_{min}$ and $T_{max}$ indicated a rising trend at a rate of 0.076 and 0.071 $^oC\ a^{-1}$. Thus, the changes in temperature and precipitation may be the major causes of accelerating the glacier ablation. The higher area changes (53.0±6.0%), of small glaciers <0.5 $km^2$ mark their sensitivity to climatic changes especially rising temperature. Under the warming climate, formation and progressive expansion of glacial lakes is expected due to the glacier recession in the basin. For instance, the Baspa Bamak Proglacial Lake at the snout of Baspa Bamak glacier has expanded continuously from 2000 onwards. A view of glacial changes in a part of the Beas basin (1980 – 2016) is shown in Figure 2.27.

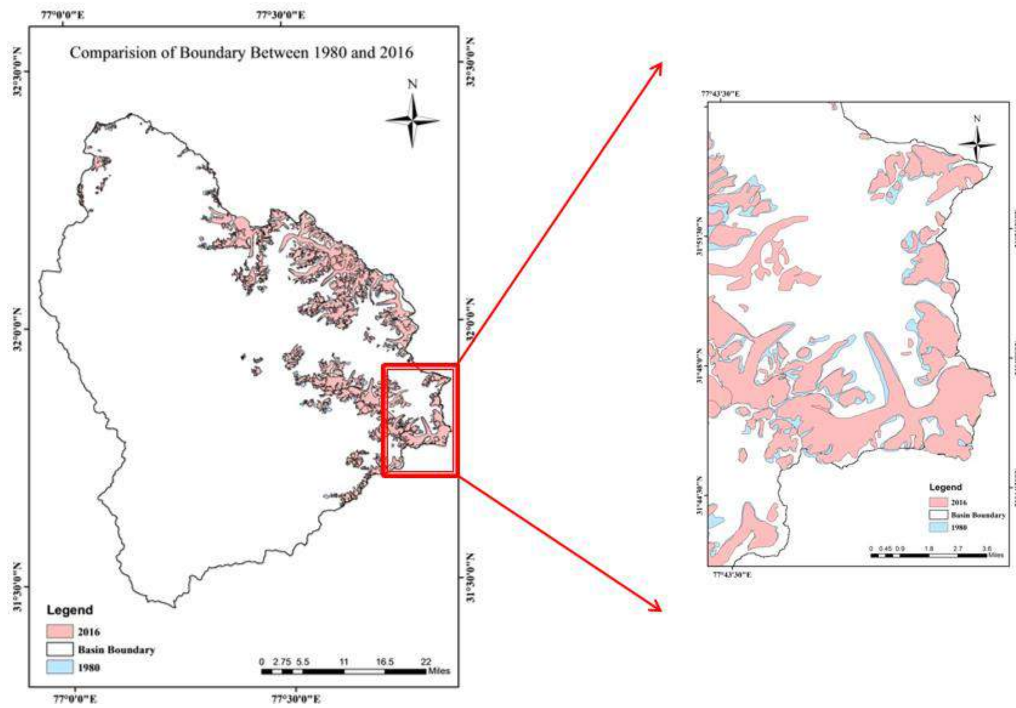


**Figure 2.27. Glacial changes observed in satellite images in a part of Beas basin**

A number of GLOF studies have been carried out at NIH for river basins of Teesta, Dhauliganga, Twang and Bhutan. As such, no lake is potentially dangerous in Dhauliganga where as some lakes are vulnerable in Teesta, Twang and basins in Bhutan. Some of the PDGLs identified in western Himalayas in different basins are shown in Figure 2.28.

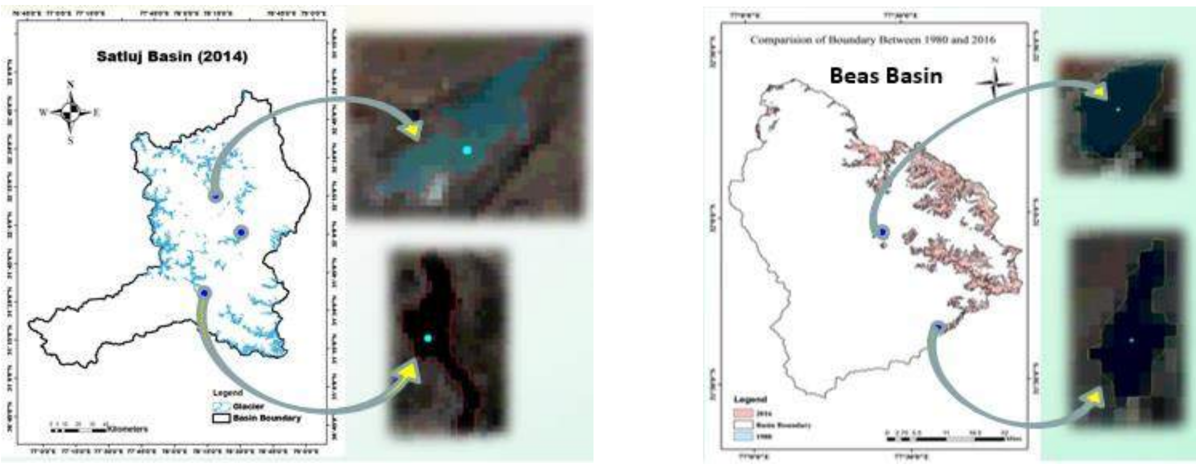


**Figure 2.28. Some PDGL identified in Satluj and Beas basins**

## A brief overview of the NMSHE Task Force projects under progress

**I. *Isotopic Investigations In The Upper Ganga Basin Up To Rishikesh revealed the following:***

- The Ganga Basin has Local Meteoric Water Line (LMWL) close to Global Meteoric Water Line (GMWL)
- Bhagirathi river is more depleted than Alaknanda, due to less rainfall in Bhagirathi basin compared to Alaknanda, and more glacial melt contribution in Bhagirathi river
- Comparing the depleated values of hot springs with other springs at the similar altitudes indicateds that the recharge of these hot springs is from relatively higher altitudes compared to the other springs.
- Groundwater (springs and handpumps) at higher altitudes are depleted compared to groundwater at lower altitudes. Depletion is higher above 2000 m than those between 1000 to 2000 m. Isotopic composition of groundwater below 1000 m is relatively enriched as it is getting recharged from rains at lower altitudes which are relatively enriched
- Altitudinal variation in the geochemical characterstics of groundwater was observed indicating precipitation dominance at higher altitude due to rock dominance at lower and middle altitude.

**II. *Environmental Assessment of Aquatic Ecosystem of Upper Ganga Basin*:**

- Water quality assessment from locations of Gangotri, Dabrani, Uttarkashi, Devprayag, Joshimath, Karnprayag, Rudraprayag, Devprayag, Rishikesh, Haridwar showed that except for Chemical Oxygen Demand (COD) and Total Solid Suspension (TSS) the otherl parameters are well within permissible limits of river water quality. COD reported higher at lower reaches of River Ganga (below 1200 m), indicating anthropogenic pollution majorly as the effluent discharge from various industries located in the area
- TSS appeared to be decreasing from higher elevation to lower elevation. High levels of TSS at higher elevation are due to unstable and young Himalayan geology, from where silt and rocks are easily carried off. Deforestation in the catchment area of the river and rapid urbanization in river flood plains also enhances TSS
- Assessment of aquatic biodiversity and relative abundance of phytoplankton, zooplankton, benthos and piscine fauna showed that phytoplanktons are decreasing towards lower altitudes, while zooplanktons and macro-benthos are on the rise.

**III. *Questionnaire based village level survey was carried out find the water adequacy in the upper Ganga basin***

- It was found that water shortage was experienced particularly in the months of May and June (Pre-monsoon) for the villages which fall at a lower elevation zone due to the drying up of natural springs. However, at higher elevation the villagers face water shortage in the months of December and January due to freezing of pipes. A plot showing the water scare months and the number of affceted village

- 126 out of 130 villages surveyed are affected by LULC change while 108 had soil erosion issues. Majority of the villagers depend directly on rainfed agriculture and daily labour for their livelihood. About 90% of the population depend on agriculture and animal husbandry for their livelihood, whereas the rest 10% depend on small business and labour
- Agricultural productivity is declining due to climate change i.e. lower rainfall/snowfall. Traditional agricultural practices have reduced e.g shift from apple cultivation to potato cultivation due to less freezing time. This had direct negative impact on the livelihood of the villagers
- Apart from non-availbility of basic infrastructure on health and education, low income from agriculture with high risk associated in the sector is one of the major reasons contributing to the migration of people from villages. About 65% of the villages surveyed reported an increasing rate of migration in the region. Agriculture with the provision of assured irrigation facilities will drastically curb the migration as opined by the villagers

## 2.4 Implications: Assessment of possible causes

Based on the historical data, trends of a number of variables that affect the water resources availability in the Himalayan basins have been discussed. Some are independent variables that are related to the hydro-meteorology of the basins such as precipitation, temperature, snow cover area, and cloudburst/extreme events, while the others are dependent variables that not only depend on the independent variables but also on the conservation and management skills of the mankind.

In section 2.3, the trends of variables have been established from a data length of certain duration. It is interesting to note that with the change in the data length, sometimes the nature of estimated trends almost reverses (as in the case of rainfall at the Srinagar station). Further, there trends are not consistent throughout the Himalayan range but can vary from region-to-region or even within a region. However if we generalize, it is seen that temperature has been rising over a considerable part of the Himalayan region though the anomalies are also observed. The possible cause of this increasing temperature seems to be more global than local. As has been predicted through various climate models, the increase in concentration of GHG in the atmosphere is responsible for the rising temperature over the whole Earth. The changes in the atmosphere also induces effect on other hydrological variables, particularly precipitation, evapo-transpiration, and atmospheric humidity.

The precipitation trends in various river basins are not consistent. The Kashmir region shows a decrease in annual precipitation and the number of rainy days while the Chenab and Satluj basins show an increasing rainfall trend. Further, the mountains in the Uttarakhand State show a mix of rising or falling precipitation trends over different recording stations. Precipitation in the Kashmir region is influenced by the alpine climate with most of the precipitation from western disturbances while the precipitation in the Chenab and Satluj basins may be influenced by both, the western disturbances and the summer monsoon. Uttarakhand experiences maximum influence from the monsoonal precipitation. Thus, in addition to the global changes, type of influencing climate and the topography of the region seem to have more pronounced effect on the precipitation in a region. The trends of snow cover area do not show any appreciable increasing or decreasing trend. From the trends of SCA in the Brahmaputra basin (Figure 2.15), it is seen that snow cover area is showing increasing trend in January while reverse trends are observed in other three seasons which could be because of increasing temperature and consequent faster melting.

As mentioned earlier, river flows are the result of precipitation, temperature, snow and glacier cover area and the utilizations and conservation of water by the mankind. In Chenab basin, the results are consistent as the rainfall and temperatures are rising and so are the river flows. In J & K, river Tawi shows a declining trend. Though no trend is available for the precipitation in Jammu region, rainfall in Kashmir had been showing declining trend which could be responsible factor for flow decline in the region. However, annual flows are declining in Satluj basin at two gauging stations which could be attributed to increased glacial cover loss in the region due to increased temperature though the area of precipitation increase is negligibly small. From the observations at the snout of Gangotri glacier for last 16 years, the annual flow show declining trend. Since no field observations are available at/above the Gangotri glacier system, the causing factor for the decreased flow is still under investigation.

## 2.5 Challenges

The trends in the hydrological and hydro-meteorological variables in different river basins of the IHR suggest that there are going to be changes in the spatial and temporal availability of water in rivers. Some of these changes are the effect of global climate impacts for which we, as an individual or as a nation, can perform our part and rest depends on the way the rest of the World reacts.

One of the most immediate challenges for our country is to conserve each and every drop of water to the extent possible and develop measures to that effect. We need to understand the price of water and develop policies which inculcate the habits of efficient and optimum use of this resource with suitably designed disposal mechanisms. We can no longer afford to consider water as a free commodity which is available infinitely and renewed every year.

## 2.6 Future directions: Strategies for more data and plans for collation

It would be worthwhile if the trends of all possible hydrological and hydro-meteorological variables are assessed for concurrent years of observations to draw some meaningful inferences and cause-effect relationships. In this light, it would be beneficial to include the data of other organizations, say SASE or State organizations, in the analysis. Since the Himalayan basins are international basins and some of their data are in classified domain, DST can assist in the acquisition of the data. Some of the short-term and long-term measures suggested are as follows:

***Short-term***

**a.** Available glacier map to be super-imposed on the habitat map of Ganga basin to identify most glacial hazard prone regions requiring immediate redressal.

**b.** Short-term forecasting of hydrological and climatological data should be displayed on the web portal which can be utilized for flash flood and water discharge forecasting.

**c.** Identification and calibration of hydrological models for optimal operation of water resources projects and evaluation of performance of water systems with different flow series generated under varying climatic conditions.
**d.** Study of Water-Energy-Climate Change relationship.

***Long-term***

**a.** Continuous mapping of snow cover and assessment along with the pattern of maximum snow cover during winter.
**b.** Strengthening of monitoring system:
   i. Monitoring of climate and snow precipitation through AWS network
   ii. Monitoring of glacial lakes, their formation and potential for hazards
   iii. Monitoring snow/ice melt and suspended sediment load
   iv. Monitoring glacier recession, volumetric changes in mass volume and snowline fluctuations for better understanding of interactions of climate
**c.** Risk and vulnerability assessment to understand the impact of climate change on glaciers and snow cover for water resources planning and management.
**d.** Integration of all the information generated for Himalayan glaciers in various projects/studies under Geographical Information System (GIS) environment. This would eventually help in effective management and planning.

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# 3 Forests and Floral Diversity

## 3.1 Background

Amongst the global mountain systems, Himalayan ranges are the youngest and loftiest, most complex and diverse both biologically and physically. The region has been recognized as one of the 35 global biodiversity hotspots. High degree of endemism in the region implies occurrence of various critical habitats and eco-regions having global importance. The Indian Himalayan Region (between 27°-38°N and 72°-89° E) includes the parts of trans, northwest, west, central and east Himalaya and covers approximately an area of 4,19,873 $km^2$ with 2500 km length and 240 km width.It comprises of five biogeographical provinces i.e., Trans (Cold deserts in Ladakh district of Jammu & Kashmir and Lahaul and Spiti of Himachal Pradesh), North West (Jammu & Kashmir and Himachal Pradesh), West (Garhwal and Kumaun), Central (Sikkim state and Darjeeling district of West Bengal) and Eastern Himalaya (Arunachal Pradesh including north-east region) (Rodger &Panwar 1988).Indian Himalayan Region (IHR), which contributes large part of hotspot, has a great ecological and economic relevance for the country on account of its enshrined values as; a climate regulator, water tower, source of major rivers, rich repository of natural capital and forests, landscape, cultural and ethnic diversity, spiritual and recreational values, and the rich source of traditional knowledge base. Its ecosystem services provide livelihood and subsistence not only to the inhabitant population but also to a large population of North Indian plains, where the settlements and economies depend on its rivers for their agriculture, household supplies and energy requirements (Saxena *et al*. 2005). However, the Himalayan ecosystem is highly vulnerable both due to geological reasons and on account of the stress caused by increased anthropogenic pressure and environmental perturbations including Climate Change (CC).

This chapter deals with the status of Himalayan forests and plant species diversity. It particularly deals with the state of forest cover, recent changes, growing stock of forests, and floral diversity across the Pan-Himalayan scale, status of invasive alien species and future strategies.

### 3.2 Methodology

The scale of assessment for the present Annual Himalayan Health was based on published data/information and field based sampling. Changes in forest cover, patchiness and fragmentation, productivity, species richness, species diversity, richness of invasive species, richness of MAPs and NTFPs have been identified as major parameters based on published literature/information. Periodic reports of Forest Survey of India (FSI) have been used to assess change in forest cover, patchiness and fragmentation, and productivity of forests of IHR states. The data on species richness and diversity is based on available information (Samant 2015). The status of threatened species is based on IUCN 2015-2016. Vulnerability of forest has been assessed based on the earlier published literature (Chaturvedi*et al.* 2010; Ravindranath*et al.* 2006), while information on invasive species also based on earlier literature. Key indicators, related parameters proposed for assessing the status of health in terms of structure and diversity of forest ecosystems are given in Table 3.1.

Species richness, stand density, basal cover, regeneration of dominant species have been identified as major indicator of change in representatives sites; for this Teesta valley in Sikkim was taken as representative site of Eastern Himalaya, and Bhagirathi valley in Uttarakhand was taken as a representative of Western Himalaya. Field based vegetation sampling was investigated through systematically dividing transect into 100 m altitude band in the representatives sites such as 1000-4000 m in Sikkim and 1000-3000 m in Bhagirathi valley. Within each band of forest, vegetation was investigated using random sampling. In each altitude band, three plots (50x50) were marked and within each plots ten (10x10 m) for trees, 20 (5x5 m) for shrubs and 40 (1x1 m) for herbs quadrates were laid randomly.The regeneration status of dominant trees was assessed based on proportional distribution of density of individuals in each seedling, sapling and adult tree class (Khan *et al*. 1987; Bhuyan*et al*. 2003); good regeneration, if seedlings > saplings > trees; fair regeneration, if seedlings > or ≤ saplings ≤ trees; fair regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = trees).

**Table 3.1: Indicators and parameters for assessing Annual Himalayan Health pertaining to forest ecosystems and floral species diversity**

| Key Indicators | Parameter | Monitoring methods | References |
|---|---|---|---|
| Forest Cover | Change in forest cover (15 yrs) | Remote sensing and GIS | FSI Report 2001-2015 |
| | Patchiness and fragmentation | Remote sensing and GIS | FSI Report 2001-2015 |
| | Growing stock of Forests | Remote sensing and GIS | FSI Report 2001-2015 |
| Species Richness and Diversity | Species richness | Published literature | Samant 2015 |
| | Species diversity | Published literature | Samant 2015 |
| Occurrence of Invasive AlienSpecies | Species richness of invasive plants | Published literature | Sekar 2012; Sekar*et al*. 2012 |
| Richness of Non-Timber Forest Products (NTFPs) | Richness of Medicinal and Aromatic Plants and other NTFPs | Published literature | Samant 2015 |
| Status of indicator species | Stand density of dominants | Field based | - |
| | Basal cover of dominants | Field based | - |
| | Regeneration status of dominants | Field based | - |
| | Vulnerability of dominant forest | Published literature | Chaturvedi*et al*. 2010; Ravindranath*et al*. 2006 |

## 3.3 Status and Trends

### *3.3.1 Status of forest cover*

IHR with 16% of geographical coverage of the country contributes 32% of India's Forest cover (i.e., 697898 $km^2$which is 21.2% of total geographical area of the country). In the IHR, states located in north eastern (NE) region have usually high forest cover above (74% of total geographical area). In Jammu & Kashmir, the total forest cover is low due to the preponderance of high elevations (75% of area in the state is above 3000 m) not suitable for forest growth (Table 3.2).

**Table 3. 2. Forest cover of IHR states and percent forest cover of geographical area (FSI 1987-2015)**

| Region/State | Percent Forest Cover of Geographical Area | | | | Contribution (%) to Forest Cover of India | |
|---|---|---|---|---|---|---|
| | % Cover in the state | | % of total forest cover in the country | | | |
| | 1987 | 2015 | 1987 | 2015 | 1987 | 2015 |
| Jammu and Kashmir | 9.4 | 10.34 (+) | 0.64 | 0.70 (+) | 3.3 | 3.3 |
| Himachal Pradesh | 22.4 | 26.40 (+) | 0.38 | 0.45 (+) | 1.9 | 2.1 |
| Uttarakhand | N.A. (Erstwhile UP Hills) | 45.32 | - | 0.74 | - | 3.5 |
| Sikkim | 38.8 | 47.31 (+) | 0.08 | 0.10 (+) | 0.4 | 0.5 |
| Arunachal Pradesh | 76.6 | 80.30 (+) | 1.95 | 2.05 (+) | 10.0 | 9.6 |
| Manipur | 78.3 | 76.11 (-) | 0.53 | 0.52 (-) | 2.7 | 2.4 |
| Meghalaya | 73.4 | 76.76 (+) | 0.50 | 0.52 (+) | 2.6 | 2.5 |
| Mizoram | 90.5 | 88.93 (-) | 0.58 | 0.57 (-) | 3.0 | 2.7 |
| Nagaland | 86.8 | 78.21 (-) | 0.44 | 0.39 (-) | 2.2 | 1.9 |
| Tripura | 56.8 | 74.49 (+) | 0.18 | 0.24 (+) | 0.9 | 1.1 |
| West Bengal Hills | NA | 61.00 | - | 0.42 | - | 0.3 |
| Assam Hills | NA | 16.59 | - | 0.40 | - | 1.9 |
| Overall % Cover in IHR | - | 32.48 | 5.28 | 6.74 | 27.1 | 32.48 |

As per FSI 2015 report, an increase in terms of absolute area in forest cover between 2001 and 2015 was found maximum (1,751 $km^2$) for J&K state, due to conversion of scrubs into forest(Figure 3.1). In this time frame total forest cover has decreased in the following states- Arunachal Pradesh (-2.8%), Nagaland (-1.2%)and a minimal decrease in Assam Hills (-0.1%; Figure 3.2). A positive change in forest cover has been observed for Meghalaya due to conservation policies leading to regeneration and afforestation. Forest encroachments for agriculture practices also become a cause of decline in forest cover of Eastern States. There was a decline in total forest cover in the states of Nagaland, Arunachal Pradesh and Assam

Hills indicating the use of wood that is utilized for construction of walls, has increased in these states. In Arunachal Pradesh, the major reasons for the decrease (73 $km^2$) are diversion of forested land for development purposes and shifting cultivation. But there is still positive change in some species due to Bamboo regeneration. In Sikkim, Meghalaya, Tripura Manipur and Nagaland the dense forest cover percent has increased.On the other hand, the forest cover of Uttarakhand decreased due to rotational felling, overexploitation of forest biomass and diversion of forest land for development activities.

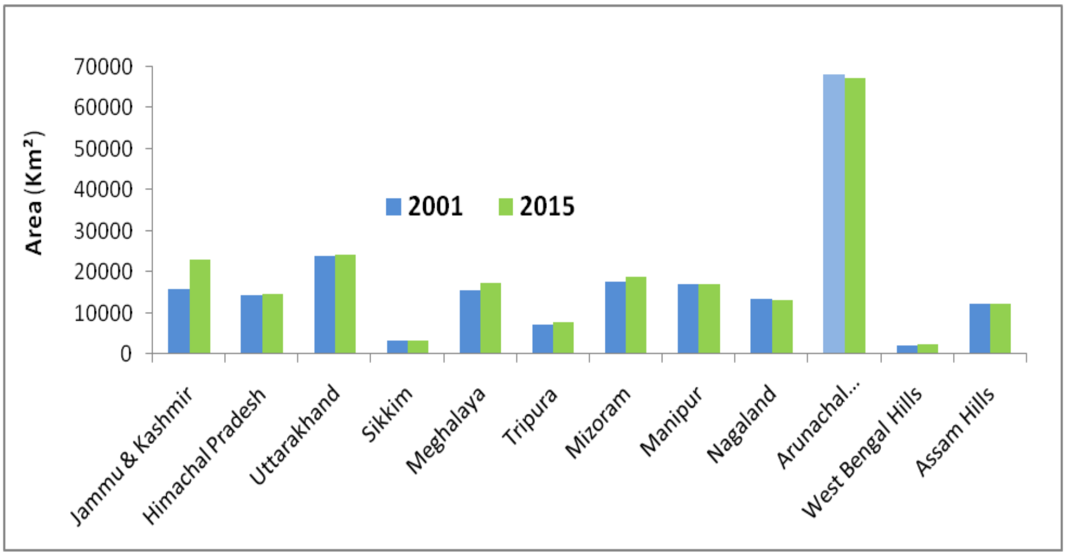


**Figure 3.1. Forest cover changes (area in $km^2$) in last 15 years in the IHR (FSI 2001 and 2015)**

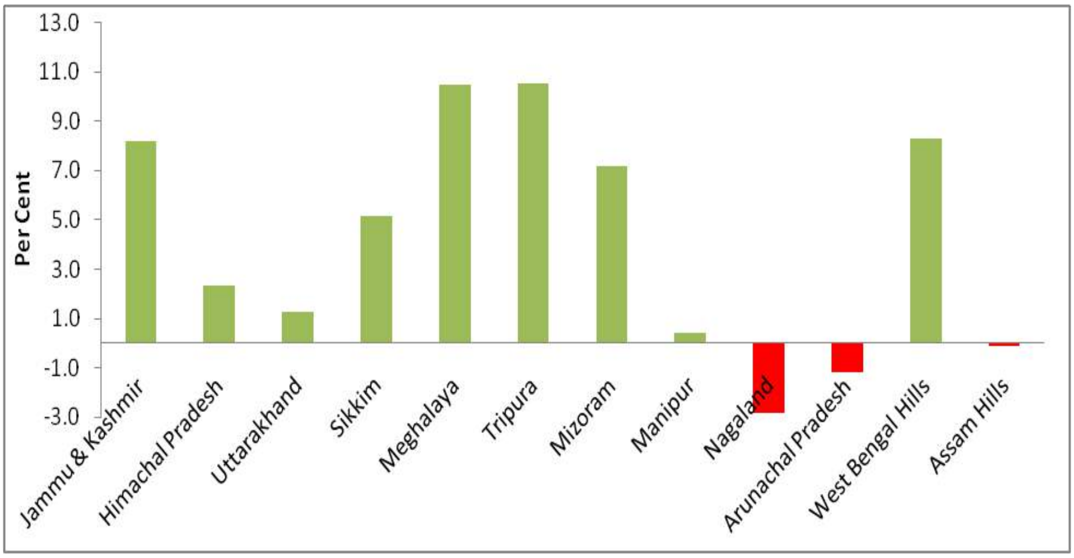


**Figure 3.2. Forest covers changes (%) between 2001-2015 in IHR states (FSI 2001 and 2015)**

In the IHR, both open and dense forest cover has increased by 0.28% and 0.71%, respectively, from 2001 to 2015 (Figure 3.3). Here open forest defines as the forest having canopy cover < 40%, moderate forest between 40-70% and dense forest >70% according FSI.In Himachal Pradesh, Uttarakhand and Mizoram the open forest coverincreased probably due to past plantation activities which have turned into forests, however, thin density and dense forest canopy hasdecreased consistently due to removal of biomass (Figure 4). In Meghalaya and Tripura, the dense forest has increased indicating that open forest cover was converted into dense forest. This could be due to fast growing species occurring in the NE Himalaya (Figure 3.4). In Nagaland the open forest has possibly disappeared and along with decrease in moderate forest; main reason of decrease was biotic pressure on forests. In Arunachal Pradesh and Assam Hills dense forest cover disappeared, open forest increased and moderate forest decreased.

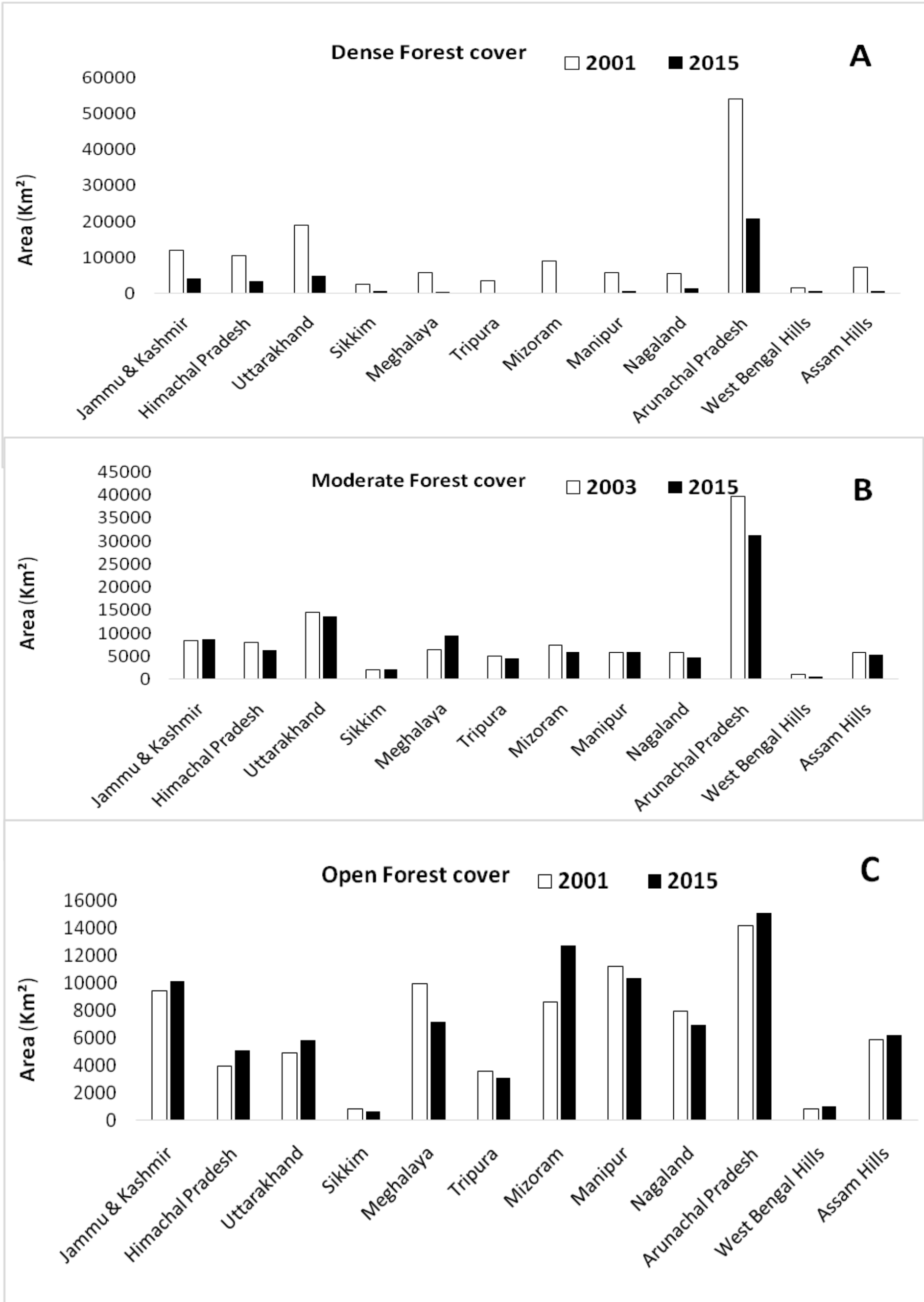


**Figure 3.3. Changes in Dense forest (A), Moderate forest (B) and Open forest (C) in IHR States between 2003 and 2015 (for moderate base year is 2003) (FSI 2001 and 2015)**

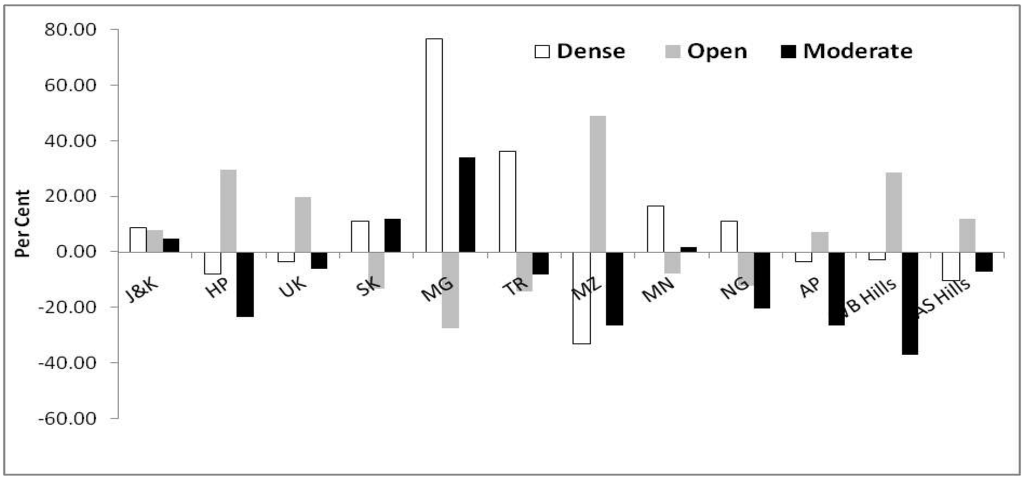


**Figure 3.4. Percent increase/decrease change in IHR between 2001 and 2015 (FSI 2001 and 2015)**

### *3.3.2 Growing Stock of the Forests in IHR States*

While forest cover is the aerial extents of country's forest, growing stock is a measure of the substance of its tree wealth (FSI 2015). Growing stock in forest, classified by forest type and by availability for wood supply, and balance between net annual increment and annual felling of wood on forest available for wood supply. Maximum growing stock in forest area (in both forest area and TOF) was found maximum for Arunachal Pradesh followed by Uttarakhand and J&K (Table 3.3). The growing stock of Uttarakhand, Tripura and Mizoram has been enhanced in 2015 as compared to 2003, while decreased for other states of IHR. The overall growing stock of Western Himalayan region has increased as compared to Eastern Himalayan region (Table 3.4).

**Table 3.3. Growing Stock (million cum) of IHR States (FSI, 2003-2015)**

| **IHR States** | Growing Stock (million cum) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2013 | 2011 | 2009 | 2003 |
| Jammu & Kashmir | 383.90 | 377.25 | 375.13 | 404.59 | 335.63 |
| Himachal Pradesh | 338.58 | 338.06 | 342.46 | 343.63 | 351.84 |
| Uttarakhand | 460.28 | 492.42 | 481.01 | 478.60 | 441.64 |
| Sikkim | 27.31 | 26.26 | 20.85 | 22.35 | 33.618 |
| Meghalaya | 58.80 | 59.93 | 66.38 | 68.45 | 84.96 |
| Tripura | 29.81 | 29.78 | 29.26 | 30.25 | 17.16 |
| Mizoram | 69.50 | 67.52 | 77.43 | 78.86 | 63.45 |
| Manipur | 60.40 | 59.66 | 81.57 | 78.85 | 115.35 |
| Nagaland | 49.05 | 48.97 | 53.64 | 55.08 | 61.99 |
| Arunachal Pradesh | 502.22 | 527.45 | 567.21 | 571.73 | 633.03 |

**Table 3.4. Comparative Growing Stock (million cum) of Western and Eastern Himalaya (FSI 2003- 2015)**

| Sub-region | Growing Stock (million cum) | | | | | |
|---|---|---|---|---|---|---|
| | 2015 | 2013 | 2011 | 2009 | 2005 | 2003 |
| Western Himalaya | 1173.437 | 1193.739 | 1198.6 | 1213.03 | 1170.44 | 1159.88 |
| Eastern Himalaya | 492.758 | 520.927 | 819.562 | 542.55 | 567.834 | 549.354 |

### *3.3.3 Plant Species Richness*

IHR harbours about 8000 species (47.06 % of the total flowering plants of India). Of which, 30% are endemic, 10.2 % trees, 8.44 % wild edibles and over 15 % medicinal (Table 3.4). Species richness and diversity was found to be maximum in tropical regions and sub-tropical regions (<1800m), followed by temperate region (1801-2800m), sub-alpine (2801-3800m) and alpine (>3800m) regions.The altitudinal zone of <1800m altitude supports about 4100 species, followed by 3300 species in the zone 1801-2800m, 2500 species in zone 2801-3800m, and 1500 species in the zone >3800m (Samant 2015) .

**Table 3.5.Species Richness in Indian Himalayan Region (FSI 2017)**

| Category | Representation | |
|---|---|---|
| | **Total number** | **% of India** |
| Angiosperms | 8000 | 47 |
| Gymnosperms | 44 | 81 |
| Pteridophytes | 600 | 59 |
| Bryophytes | 1737 | 61 |
| Lichens | 1159 | 59 |
| Fungi | 6900 | 53 |
| Specific groups | | |
| Medicinal | 1748 | 23 |
| Wild edibles | 675 | 67 |
| Trees | 723 | 28 |

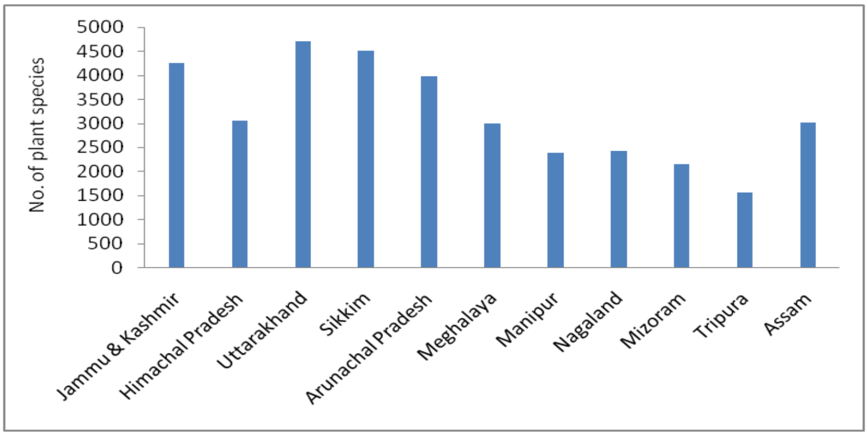


**Figure 3.5. Species Richness in IHR States**

### *3.3.4 Species Richness in Western Himalaya*

Himachal Pradesh (HP) supports 3400 plant species, of which 323 are tree species, 543 shrub species and > 3000 herb species (Fig. 3.5). Asteraceae, Poaceae, Fabaceae, Rosaceae, Scrophulariaceae, Lamiaceae, Ranunculaceae, Cyperaceae, Orchidaceae, Apiaceae, etc. are the most dominant families in HP. J&Ksupports about 4,000 plant species, of which about 280 tree species, 573 shrub species and > 3000 herb species have been recorded from the state. About 880 species are found in Ladakh and 506 species in Jammu district. Asteraceae, Poaceae, Fabaceae, Rosaceae, Cyperaceae, Lamiaceae, Brassicaceae, etc. are the most dominant families in J&K. Uttarakhand (UK) supports over 5000 species of Angiosperms, of which 538 are trees, 900 shrubs and > 4500 herbs. Asteraceae, Poaceae, Fabaceae, Orchidaceae, Cyperaceae, Rosaceae, Scrophulariaceae, Lamiaceae, Ranunculaceae, Apiaceae, etc. are the most dominant families in UK. Dominant families have significance for the ecosystem health as in each ecosystem; these families form the major part. Nativity, endemism, economic importance and threat status of the species play an important role for the identification of ecosystem health.

### *3.3.5 Species Richness in Eastern Himalaya (including NE region)*

The region has been in focus for its rich biodiversity, and has remained a priority area for activities of leading conservation agencies. The north-eastern region is the richest in terms of biological wealth and approximately supports about 8500 species of flowering plants (Fig. 3.5). Among various states of Northeast region maximum species richness has been estimated in Sikkim state having about 4,524 species, followed by Arunachal Pradesh (4146), Meghalaya (3128), Assam (3017), Nagaland (2440), Manipur (2381), Mizoram(2147) and Tripura (1476) according to Rao and Murti (1990); Upadhaya*et al*. (2012) given in Figure 3.2.

### *3.3.6 Threat Status of Plants*

Of the total 456 threatened species listed in IHR, 13 (2.7%) species are Critically Endangered (CR)*;* 27 species (6%) Endangered (EN), 8 (1.9%)species Near Threatened (NT), 23 (5%) species Vulnerable (VU), 356 (78%) species Least Concern (LC) and 28 (6.1%) species Data Deficient (DD). As per IUCN database, 01 species (0.2%) i.e. *Sterculiakhasiana*Deb is thought to be Extinct. State wise break up of these species are given in Tables 5 (Growth habits) and (6 Threat Categories). Western Himalaya has 411 species listed under Red Data Book of IUCN. Growth habits and Threat categories of these species across three states are given in Tables 3.6 and 3.7 respectively.

**Table 3.6. Status of threatened plants species in Western Himalaya (IUCN, 2016)**

| Life-form | J&K | HP | UK |
|---|---|---|---|
| Herb | 96 | 82 | 44 |
| Shrub | 20 | 23 | 12 |
| Tree | 21 | 38 | 24 |
| Climber | 8 | 14 | 9 |

**Table 3.7. Threat status of plant species of Western Himalayan (IUCN, 2016)**

| Criteria | J&K | HP | UK |
|---|---|---|---|
| Extinct (EX) | - | - | - |
| Extinct in Wild (Ex W) | - | - | - |
| Critically Endangered (CR) | 4 | 5 | 2 |
| Endangered (EN) | 3 | 9 | 3 |
| Vulnerable (VU) | 3 | 8 | 9 |
| Near Threatened (NT) | 5 | 5 | 10 |
| Least Concern (LC) | 128 | 117 | 61 |
| Data Deficient (DD) | 10 | 13 | 4 |

Threat status of plants in Eastern Himalaya and North-eastern Hill states are given in Tables 8 (growth habit) and 9 (Threat Categories). It is noteworthy that Sikkim has highest number of threatened herbs (195) followed by Mizoram (92) and Arunachal Pradesh (79).

**Table 3.8. Status of threatened plants speciesin Eastern Himalayan region of IHR (IUCN, 2016)**

| Life-form | Assam (AS) | Arunachal Pradesh (AR) | Manipur (MN) | Meghalaya (ML) | Mizoram (MZ) | Nagaland (NL) | Sikkim (SK) | Tripura (TR) | West Bengal (WB) |
|---|---|---|---|---|---|---|---|---|---|
| **Herb** | 42 | 79 | 64 | 60 | 92 | 78 | 195 | 60 | 17 |
| **Shrub** | 12 | 17 | 9 | 20 | 23 | 23 | 17 | 20 | 0 |
| **Tree** | 20 | 35 | 29 | 14 | 43 | 33 | 53 | 14 | 0 |
| **Climber** | 11 | 12 | 5 | 7 | 4 | 11 | 6 | 7 | 7 |

**Table 3.9. Threat status of plants of Eastern Himalayan region of IHR (IUCN, 2016)**

| Criteria | AS | AR | MN | ML | MZ | NL | SK | TR | WB |
|---|---|---|---|---|---|---|---|---|---|
| Extinct (EX) | - | - | - | - | - | - | - | - | - |
| Extinct in Wild (Ex W) | - | - | - | 1 | - | - | - | - | - |
| Critically Endangered (CR) | 5 | 8 | 3 | 2 | 4 | 3 | 3 | 2 | - |
| Endangered (EN) | 8 | 10 | 5 | 1 | 4 | 6 | 11 | 1 | - |
| Vulnerable (VU) | 5 | 5 | 6 | 3 | 6 | 12 | 6 | 2 | 9 |
| Near Threatened (NT) | 16 | 3 | 4 | 5 | 4 | 9 | 3 | 4 | |
| Least Concern (LC) | 45 | 110 | 85 | 92 | 140 | 102 | 226 | 83 | 91 |
| Data Deficient (DD) | 10 | 7 | 4 | 16 | 4 | 13 | 22 | 8 | |

### *3.3.7 Trends in Species Richness, Density and Regeneration Status along altitudinal gradients*

**a) *Species Richness***

Along Bhagirathi Valley, maximum species richness (29) was found at 2100 m and minimum (13) at 1000 m (Figure 6). Maximum tree species richness (14) was found between 2000-2100 m while minimum (3) at 1000 m (Figure 3.6).

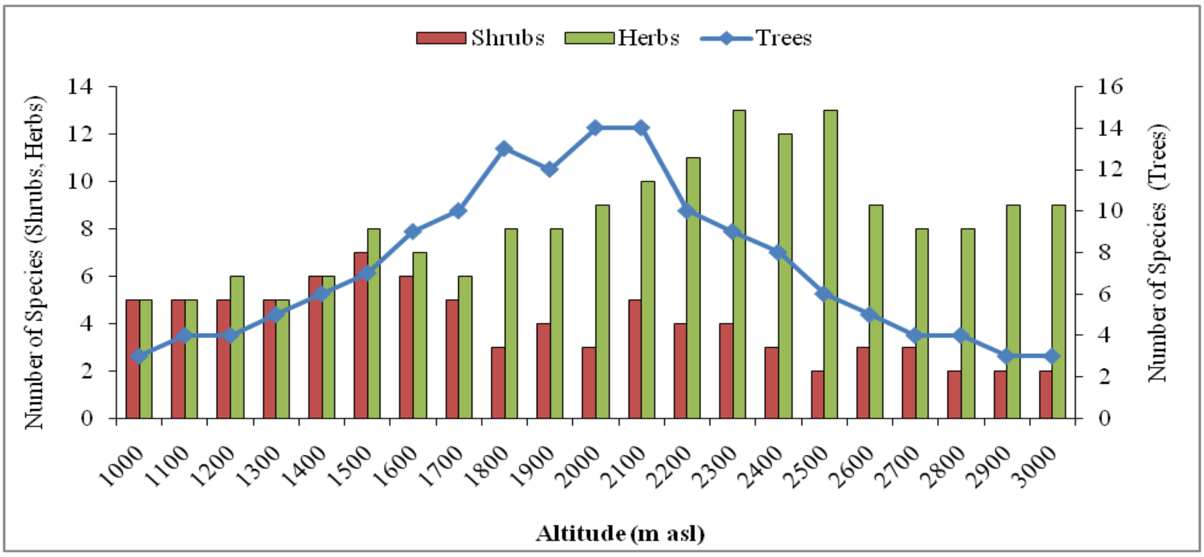


**Figure 3.6. Species richness trends along altitudinal range in Western Himalaya**

In Teesta Valley, highest species richness (47) was found at1300 m and minimum (23) at 4000 m (Figure 3.7). Maximum tree species richness (17) was found at 1300 m while minimum (3) between3900-4000 m altitude.

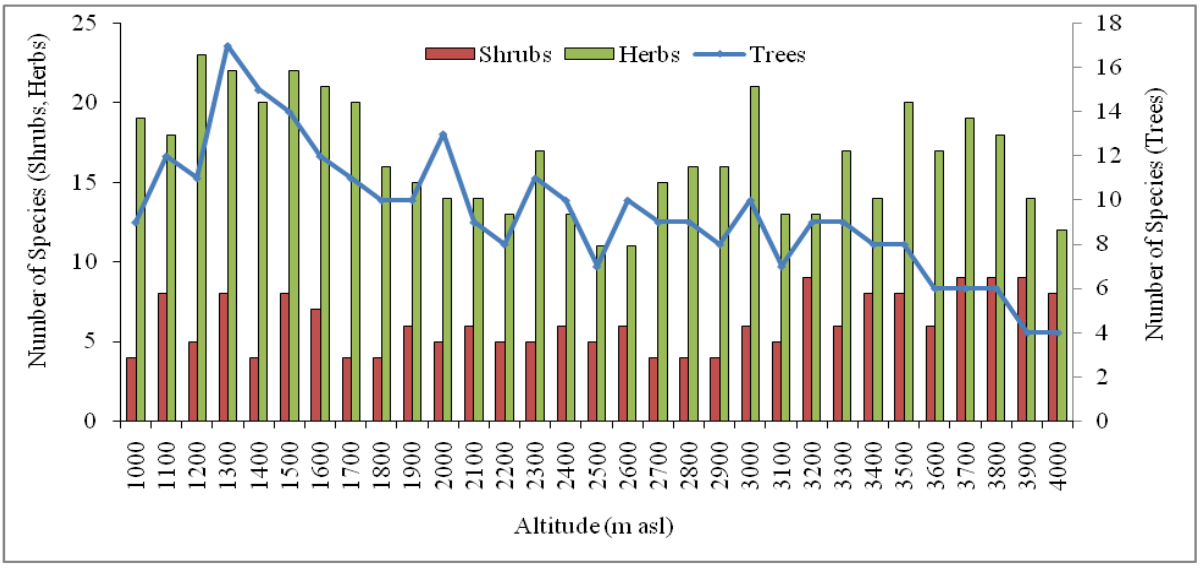


**Figure 3.7. Species richness trends along altitudinal range in Eastern Himalaya**

### *b) Trends in density of plants*

In Bhagirathi Valley, maximum density of trees (1930 Ind/ha) was found at lower (2100 m) and minimum (680 Ind/ha) at 1000 m. Shrub density was maximum (3360 Ind/ha) at 1500m and minimum (780 Ind/ha) at 2800m. The density of plant species increased upto 3000 m in Bhagirathi valley of western Himalaya, while it was decreased after 3100 m along the altitudinal transect (Figure 3.8).

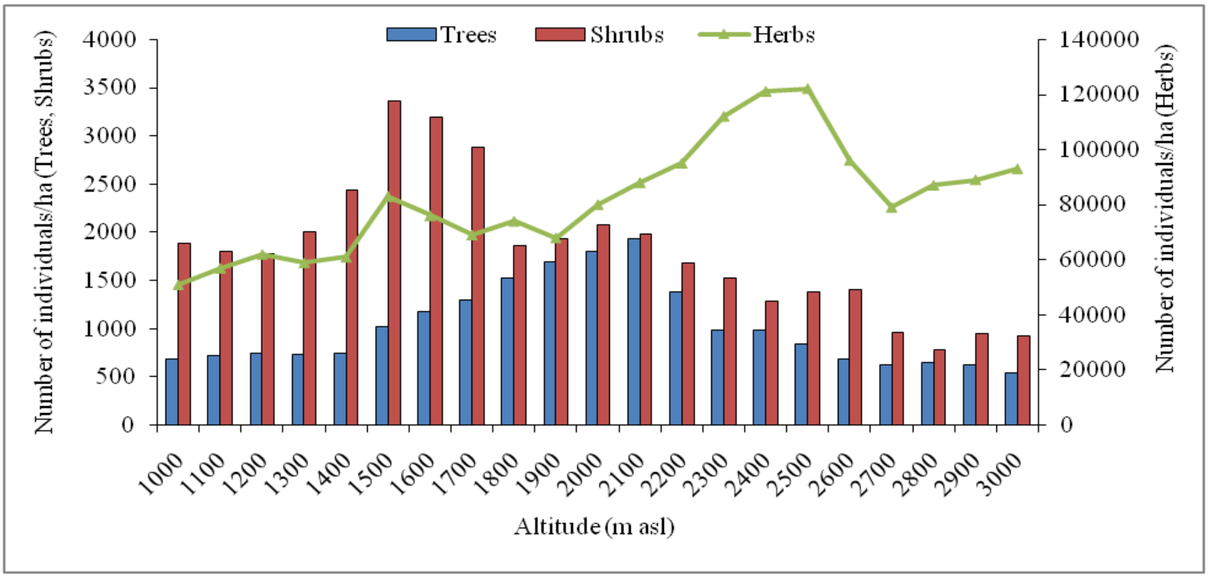


**Figure 3.8. Stand density of plant species along altitudinal range in Western Himalaya**

In Teesta Valley maximum tree density (1150 Ind/ha) was found at lower (1300 m) altitude while minimum (520 Ind/ha) at 2200 m. Similarly maximum density of shrubs (3480 Ind/ha) was found at 1100 m and minimum (1300 Ind/ha) at 1800m (Figure 3.9).

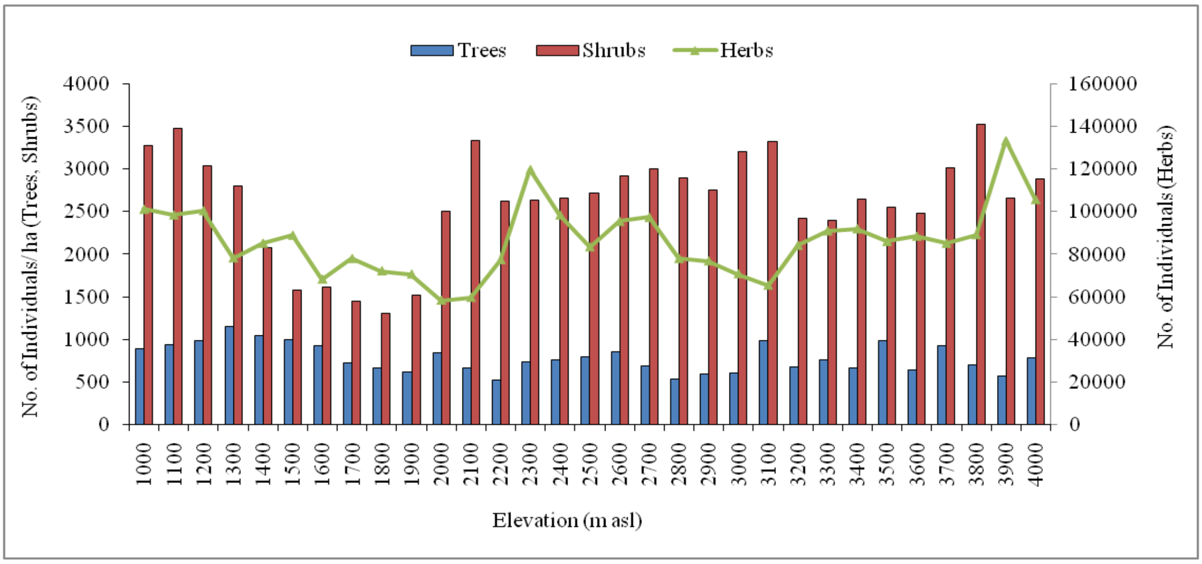


**Figure 3.9. Stand density of plant species along altitudinal range in Eastern Himalaya**

### *c) Trends in regeneration and basal cover*

In Bhagirathi Valley, the regeneration of tree species was found fair at most of the attitudes, while it was found poor at 1800m, 2200m, 2400m altitude (Figure 3.10). At the lower altitude strata (<1500 m) the dominant trees had low proportion of saplings and seedlings. However, the regeneration of tree species was found comparatively well at higher altitudes (3500-3800). The basal area ranged between 10.11m$^2$/ha to 91.73m$^2$/ha along the altitudinal gradient with maximum (91.73) at 2300 m altitude and minimum (10.11) at 1100m (Figure 3.11).

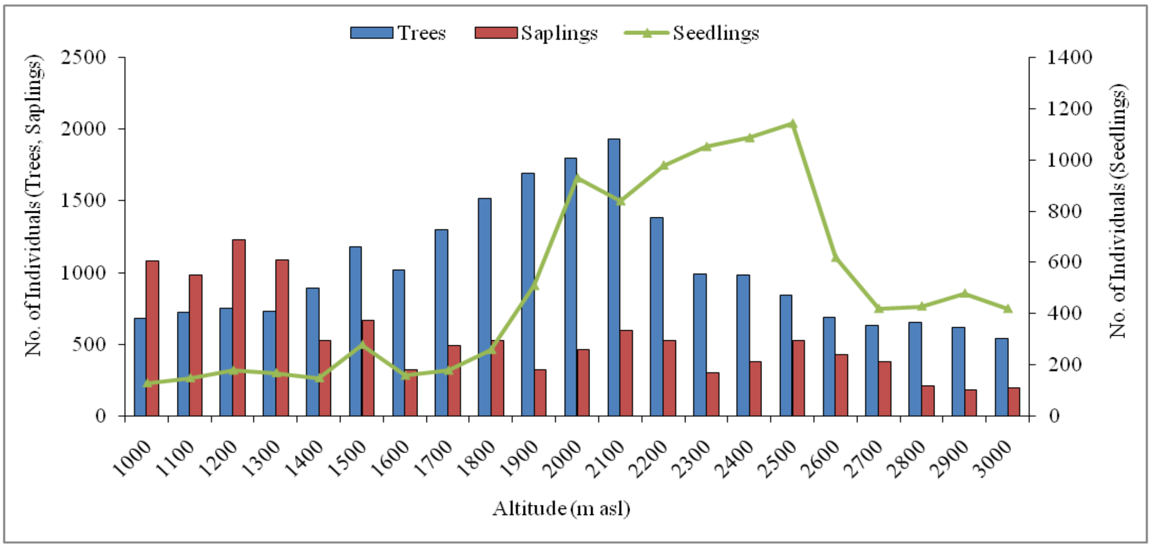


**Figure 3.10. Trends of regeneration along altitudinal range in Western Himalaya**

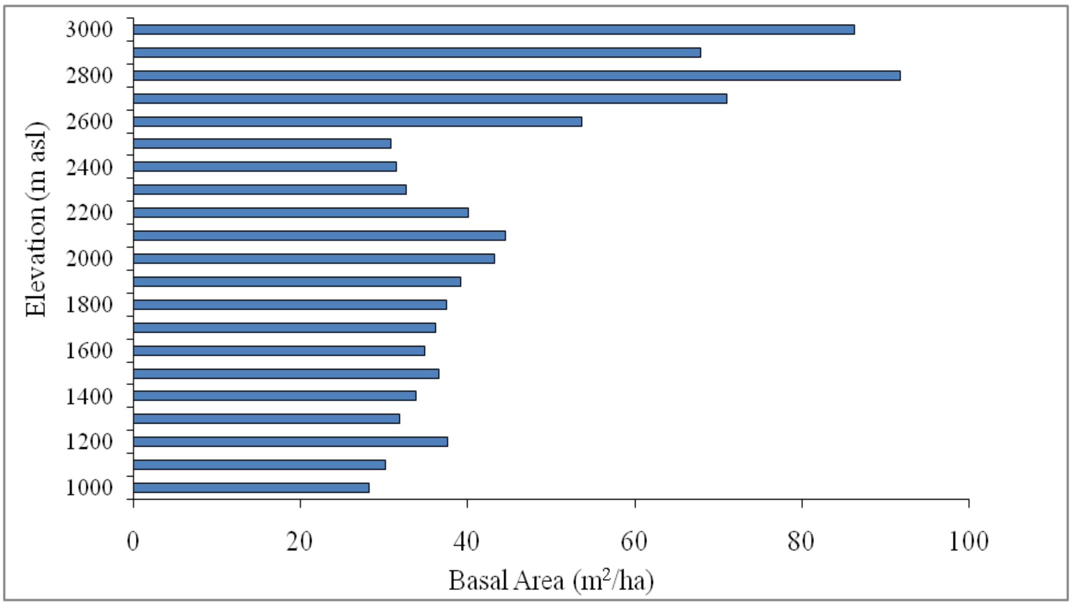


**Figure 11. Trends of basal cover ($m^2$/ha)of tree species along altitudinal range in Western Himalaya**

The regeneration of tree species was found fair at most of the attitudes, while it was found poor at 1800m, 2200m and 2400m altitude transect (Figure 3.12). The regeneration of tree species was found comparatively good at higher altitudes (3500-3800 m). The basal area ranged between 6.39$m^2$/ha to 36.06 $m^2$/ha along the altitudinal gradient in eastern Himalaya. The basal area was found maximum (91.73) at 1100 m and minimum (10.11) at 2100m (Figure 3.13).

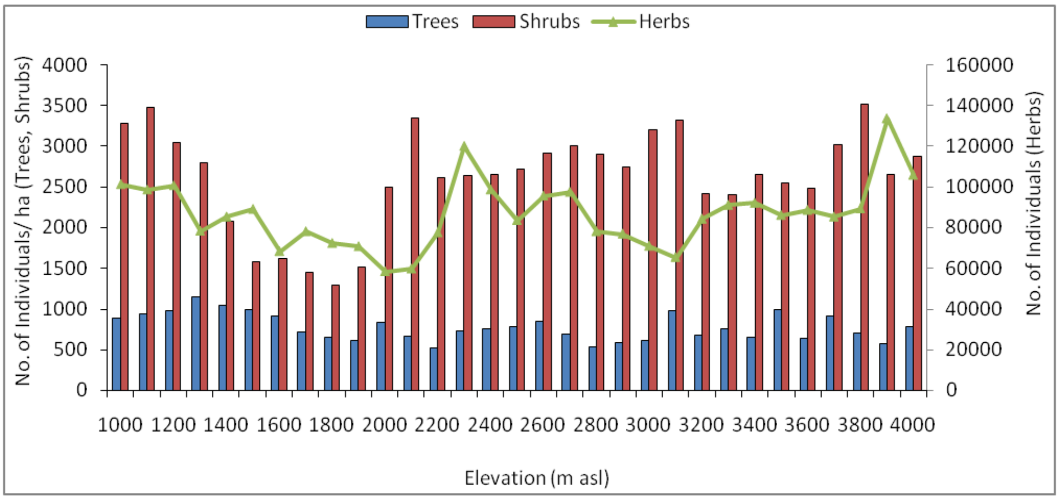


**Figure 3.12. Trends of regeneration along altitudinal range in Eastern Himalaya**

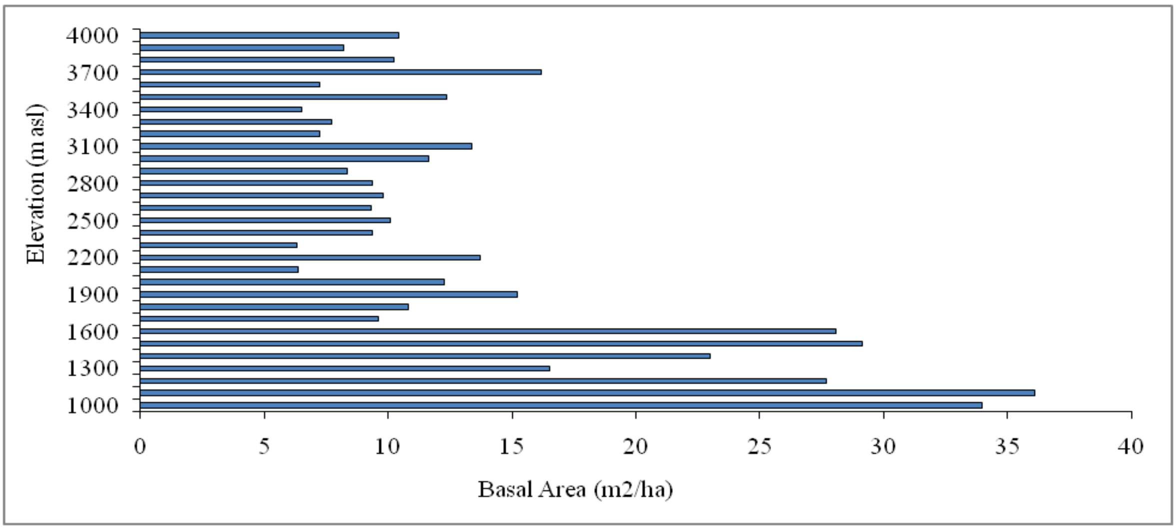


**Figure 3.13. Trends of basal cover ($m^2$/ha)along altitudinal range in Eastern Himalaya**

### *3.3.8 Richness and availability of Medicinal and Aromatic Plants and other Non-timber Forest Products (NTFPs)*

A total of 1748 species of medicinal and aromatic plants (191 families, 878 genera and 1685 species of angiosperms), Gymnosperms (4 families, 6 genera and 12 species) and Pteridophytes (28 families, 31 genera and 51 species), have been recorded from IHR (Samant*et al*. 1998). Of which 339 were trees, 338 shrubs, 1020 herb and 51 were the fern species. Among other NTFPs, nearly 675 wild edibles belonging to 348 genera and 149 families of Angiosperms (127 families, 361 genera and 647 species), Gymnosperms (5 families, 6 genera and 7 species), Pteridophytes (9 families, 9 genera and 12 species), Fungi (6 families, 6 genera and 7 species) and Lichens (2 families, 2 genera, 2 species) have been reported for IHR (Table 3.10).Rosaceae, Polygonaceae, Moraceae, Asteraceae, Fabaceae, etc. were dominant families rich in wild edibles. A total of 513 species were recorded from Western Himalaya while 394 species recorded from Eastern Himalaya (Samant 2015).

**Table 3.10. Use of wild species by local communities in IHR**

| Category | Western Himalaya | | | Eastern Himalaya | | |
|---|---|---|---|---|---|---|
| | **J&K** | **HP** | **UK** | **SK** | **WB hills** | **AR** |
| Medicinal & Aromatic Plants | 580 | 650 | 701 | 707 | 450 | 650 |
| Wild vegetables | 20 | 18 | 27 | 11 | 11 | 79 |
| Wild fruits | 18 | 17 | 58 | 14 | 14 | 36 |
| Edible mushrooms | 3 | 4 | 26 | 10 | 10 | 15 |
| Edible pith/flowers | N.A. | 7 | 19 | 13 | 13 | N.A. |
| Dye and colour fixer | 7 | 6 | 4 | 7 | 7 | 39 |
| Spices and condiments | 5 | 4 | 10 | 14 | 14 | 62 |
| Small Timber | 16 | 15 | 14 | 24 | 24 | 40 |
| Thatching | 6 | 9 | 2 | 2 | 2 | 8 |
| Fuel wood | 22 | 11 | 28 | 48 | 48 | 37 |
| Fodder | 50 | 47 | 44 | 50 | 48 | 24 |
| Paper, pulp and fiber | 3 | 2 | 9 | 2 | 2 | N.A. |
| Hunting and piscicide | 2 | 3 | 1 | 7 | 7 | 60 |
| Gum, resin and tannin | 3 | 3 | N.A. | 7 | 8 | 3 |
| Incense and aroma | 10 | 8 | 4 | 5 | 5 | N.A. |
| Oil yielding | 8 | 8 | 11 | 16 | 16 | 4 |
| Local and beverages | 5 | 3 | N.A. | 8 | 7 | N.A. |

### *3.3.9 Status of invasive alien plants in IHR*

A total of 190 invasive alien species under 112 genera, belonging to 47 families has been recorded from IHR (Sekar 2012). Among, invasive species, herbs are dominant (148 species), followed by shrubs (19 species), grass (11 species), trees (4 species), sedges and climber (3 species each). The genera with the highest number of alien invasive species in IHR are *Ipomoea* (10 species); *Cassia* (9 sp.); *Alternanthera*, *Corchorus*and *Solanum*(5 sp. each); *Cleome*, *Euphorbia*, *Indigofera*and *Datura*(4 sp. each). The family Asteraceae is the most dominant family with 31 species; followed by Solanaceae (15 sp.); Convolvulaceae and Fabaceae (13 sp. each). Among various invasive species, *Lantana camara, Ageratinaeupatoria*and *Partheniumhysterophorus*, *Ageratum conyzoides*have spread over large areas in the mountains of IHR and negatively impacting the plant diversity but also their biological integrity (Kosaka*et al.*, 2010). *Lantana camara* has encroached upon large areas of land, especially the forests where it has virtually replaced the forest floor vegetation and reduced tree growth. *Ageratinaeupatoria* has spread in moist area of road and forest ecosystem in IHR and impacting the plant diversity by increasing its competitive advantage through allelopathic action and by altering soil microbial communities (Dhyani 1978).*Ageratum conyzoides* has invaded agricultural fields in most of the states of IHR and causes yield reductions of major staple crops. Amongst 190 invasive alien plant species recorded from IHR, *Eupatorium adenophorum*has beenreported as invasive largely in Eastern Himalaya (Tripathi and Yadav 1982). However, over the years, it has also got naturalized in western parts of IHR (Bughani*et al*. 2005).

**Model based assessment of Climate Change impacts on vegetation distribution and forest resources in Indian Himalayan Region**

1. The forests in the central part of India, especially the north-western part of India are highly vulnerable. There are regions of vulnerability surrounded by non-vulnerable regions in that area (Chaturvedi *et al*. 2010). A spatial presentation of forest shift projected by the Input/output Buffer Information Specification (IBIS) model in the mid (2030s) and long term (2080s) under RCP4.5 and 8.5.
2. A significant part of the Himalayan bio-diversity hotspot that stretches along the northwestern part of India along the states of Jammu and Kashmir and Himachal Pradesh is projected to be highly vulnerable to climate change (Chaturvedi *et al*. 2010).This may be mostly attributed to the higher elevation of these regions. Similarly, a substantial forest area under temperate evergreen forest category of Jammu and Kashmir is expected to be colonized by temperate deciduous forest by 2030s (Ravindranath *et al*. 2006). Moreover, expansion of savannahs, reappearance of temperate evergreen coniferous forest and shrub lands in Karakoram belt is expected under RCP 4.5 and 8.5 climate change scenario by 2080s.
3. Forests of Mandi, Bilaspur, Solan, and Simmaur districts of Himachal Pradesh has been (Western Himalaya) found to be highly vulnerable; whereas forests of Lahul-Spiti, Kullu and Kinnaur districts to be less vulnerable in current climate scenario. Forests of Chamba, Kullu, Mandi, Shimla and Kinnaur districts of Himachal Pradesh are expected to shift from the existing forest type under RCP 4.5 climate change scenario by 2030s. Similarly, forests of Lahul-Spiti and Kangra districts are expected to shift from existing forest type under RCP4.5 and 8.5 climate change scenario by 2080s (Ravindranath et al. 2006).
4. Over the north-east Himalayan region, an increase in forest cover of 3371 $km^2$ having an annual growth of 0.4% due to significant increase in forest cover of Arunachal Pradesh (4870 $km^2$), Sikkim (285 $km^2$), Manipur (210 $km^2$), Meghalaya (2130 $km^2$) and Mizoram (683 $km^2$) was noted during 1987-1991. Forests of western Nagaland, Mizoram, north Sikkim and east Garo hills are found to be vulnerable under RCP 4.5 and 8.5 climate change scenario by 2080s, but vulnerability is expected to reduce in Kokrazhar region of Assam (Ravindranath et al. 2006).

## 3.4 Conclusion

Overall forest cover in the IHR is 32.48%. There has been a slight increase in per cent cover of the forests in the Himalayan states but some decline in the North-eastern hill states.Overall growing stock of Western Himalayan region has increased as compared to Eastern Himalayan region. About 411 species of plants are threatened from western and Western Himalaya as compared to 1139 plant species from Eastern Himalaya. Within the intensive survey localities (vertical transects) the range of species richness was 13-29 in western Himalaya as compared to 23-47 in the eastern Himalaya. The range of tree species richness was found to be 3-14 in Western Himalaya as compared to 3-17 in Eastern Himalayaalong altitudinal gradient. Similarly the range of tree density was 520-1150 Ind/ha in Western Himalaya as compared to 680-1930 Ind/ha in eastern Himalaya.

The regeneration status of tree species was found better in Teestavalley as compared to Bhagirathi valley. A total of 190 invasive alien species under 112 genera, belonging to 47 families has been recorded from IHR. *Partheniumhysterophorus*, *Lantana camara*, *Ageratinaeupatoria*are most noxious invasive species that replacing the native vegetation, has encroached upon large areas of land, especially the forests where it has virtually replaced the forest floor vegetation and reduced tree growth. The forests in the central part of India, especially the north-western part of India are highly vulnerable. A significant part of the Himalayan bio-diversity hotspot that stretches along the northwestern part of India along the states of Jammu and Kashmir and Himachal Pradesh is projected to be highly vulnerable to climate change. However, this ecological equilibrium in the flow of material and energy and the mechanism of connections and feedbacks are being rapidly eroded by human interference with the climate system.Therefore, maintaining ecosystem resilience, while focusing on the underlying structure, functions, and processes of ecosystems, should be a priority.

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# 4 Wildlife Habitats and Faunal Diversity

## 4.1. Background

The Indian Himalayan Region (IHR) is one of the richest biodiversity regions of the world. The diverse ecological range is a result of uneven height of Himalayan Mountains ranging from 500 m to 8,000 m. Among the 34 biodiversity hotspots, four are located in the Himalayas, including the mountains of Central Asia, Himalaya, south-western China, and Indo-Burma. Of the estimated faunal species found in IHR 12 out of 300 mammal species, 48 out 176 reptile species, 15 out of 977 bird species, 42 out of 105 amphibian species and 33 out of 269 fresh water fish species are endemic (Gadil, 2008). On account of richness and uniqueness of biodiversity elements, IHR has 15 national parks and 59 sanctuaries covering 9.6% of the geographical area within Protected Area (PA) of India.

The fragile mountain ecosystem in the IHR is adversely impacted by climate change and increasing anthropogenic pressure hindering the ecological, hydrological and biological values. The alpine meadows which are the grazing and hunting sites for the species inhabiting the region premature budding and flowering of plants are occurring due to increase in temperature. Alpine habitat loss and species migration due to climate change presents threat of decrease in habitat for mega faunal species (i.e., snow leopard). The shift in the flowering patterns and budding of leaves due to shift in rainy season has led to the change in activities of insects which in turn has alters the patterns of birds and cumulatively disrupted the entire cycle of an area. Researchers at WII have identified that the Himalayan mouse hare, a kind of rodent unique to the alpine area is unable to adapt to the new environment.

In addition the wildlife of IHR are subjected to threats of anthropogenic activities like poaching for meat, illegal wildlife trade, negative human– wildlife interactions (conflicts), habitat loss, habitat fragmentation and degradation due to developmental activities and natural resource use by humans. Therefore, it is appropriate that studies are carried out to assess status of the faunal species in the IHR to monitor the health of ecosystem.

This chapter presents a bottom-up approach using a composite of systematic indicators to assess the health of the Indian Himalayan ecosystems at the coarse Pan-Himalayan and finer scales from the perspectives of key faunal species and their habitats. The indicators have been picked up based on their ecological significance in both structure and functioning of major ecosystems and their influence on wildlife habitats. The methodology adopted has been simplified for easy understanding as well as periodic observation/monitoring. This assessment does not cover thestatus of agro-ecosystems and socio-economic aspects for which different set of indicators will be needed to reflect the flow of ecosystem services.

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## 4.2. Methods and Scales

### *4.1.1 Area of Assessment*

For the purpose of present assessment we have used broad geographical area of Indian Himalayan Region (IHR) excluding north-eastern hill states (Figure 4.1). This region covers an area of about 5 lakh km$^2$ (about 16.2% of country's total geographical area). It covers six states of India, viz., Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh and the northern districts of West Bengal. Biogeographically, this region is divisible into two regions *viz*., the Himalaya and Trans-Himalaya encompassing Ladakh Mountains (1A), Changthang plateau (1B), Sikkim plateau (1C), Northwest Himalaya (2A), West Himalaya (2B), Central Himalaya (2C) and Eastern Himalaya (2D)(Rodgers *et al*. 2002). The state of West Bengal has two districts that form part of Himalaya viz., Darjeeling and Jalpaiguri and other districts have been excluded for present assessment. Table 4.1 provides area statistics, number of districts, forest cover, human population density and protected area coverage of IHR.

**Table 4.1.State-wise details of the Indian Himalayan Region.**

| Himalayan State | Geographical Area (km$^2$) | Districts | Forest Cover (%) | Population (million) | Population Density (#/km$^2$) | Protected Areas | Protected Area (%) |
|---|---|---|---|---|---|---|---|
| Jammu& Kashmir | 222,236 | 15 | 10.34 | 12.54 | 124 | 16 | 5.26 |
| Himachal Pradesh | 55673 | 12 | 26.40 | 6.86 | 123 | 35 | 17.99 |
| Uttarakhand | 53483 | 13 | 45.32 | 10.09 | 189 | 16 | 13.79 |
| Sikkim | 7096 | 4 | 47.31 | 0.61 | 86 | 8 | 30.76 |
| North Bengal | 9376 | 2 | 55.8 | 5.72 | 610 | 11 | 12.32 |
| Arunachal Pradesh | 83743 | 13 | 80.30 | 1.38 | 17 | 13 | 11.68 |

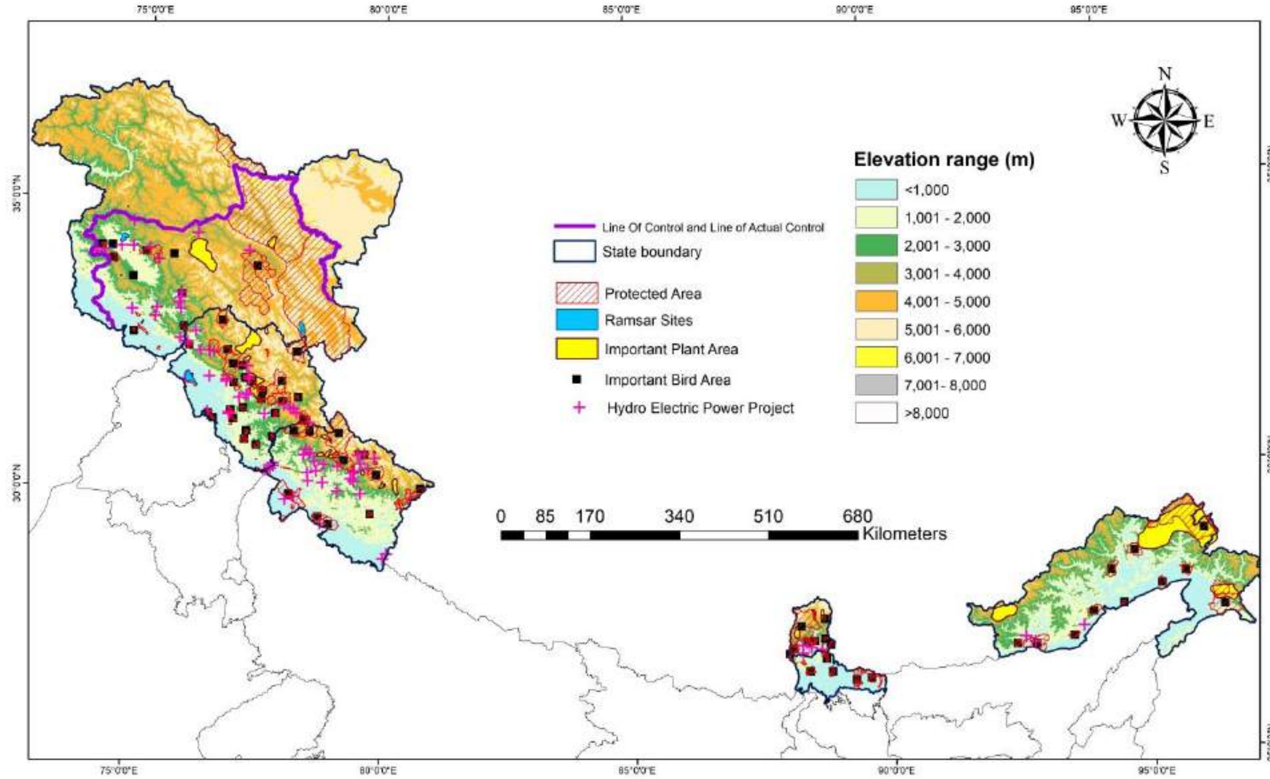



**Figure 4.1. Spatial distribution of distribution of important wildlife conservation site and hydroelectric power projects in different states of Indian Himalayan region**

### *4.1.2 Indicators of Ecosystem Health and Scales of Analysis*

This assessment is based on the premise that healthy ecosystems in any region harbour natural habitats that provide a combination of basic resources such as food, cover, water and other environmental conditions which promote occupancy by populations of native fauna. Several factors of the habitat such as primary productivity, vegetation structure, contiguity, and trophic structure thus reflect the structure and functioning of ecosystems which in turn reflect their health. For the purpose of present assessment we have selected a few indicators to be used at four spatial scales: (i) Pan-Himalaya,(ii) Five Himalayan states and northern districts of West Bengal, (iii) One river basin i.e., Bhagirathi based on intensive primary surveys; (iv)Aquatic habitats within smaller section of Bhagirathi river and a few high altitude wetlands. Depending upon the availability of information we have used various indicators at different scales i.e., broad parameters at the Pan-Himalaya (16 x 16 km grids) and finer parameters at the scale of smaller pilots (4 x 4 km) in hierarchical order.We divided these parameters into five thematic areas *viz*., (a.) hydrological integrity (b.) water quality (c.) biotic community-Flora (d.) biotic community- Fauna, and (e.) anthropogenic pressures. At the scale of river basins we recommend abundance of selected species fishes and macro-invertebrates for assessing the ecosystem health along with extent of hydro-power projects and drainage intensity.

### *4.1.3 Geo-spatial Analysis at the scales of Pan Himalaya and States*

At the Pan Himalayan scale, the entire area of IHR was divided into 16x16 km grids (n=1923). The states were sub-divided into 4x4 km cells. All the grid cells including forest and non-forest were considered for analysis and preparation of final health scores.The spatial data used in the assessment include elevation data (NASA LP DAAC, 2015), slope, forest cover (FSI, 2015), land use/land cover (Defournyet *al.*2015), productivity/NDVI (Kamel Didan, 2015) and human footprint data (Osca*et al*. 2016) (Table 4.2).

**Table 4.2**: **Details of spatial data used for Pan Himalayan assessment**

| Data layers | Spatial Resolution | Units | Data type | Source |
|---|---|---|---|---|
| Elevation | 30 m | Meters | Continuous | ASTER |
| Slope | 30 m | Degree | Continuous | Derived from elevation |
| Forest Cover | 24 m | Meter Square | Categorical | Forest Survey of India |
| Land Use/Land Cover Data 2015 | 300 m | Meter Square | Categorical | AVHRR |
| NDVI 2015 | 250 m | No unit | Continuous | NASA-MODIS |
| Human Footprint | 1 km | Percent | Continuous | WCS |

Based on literature and ecological significance, the following indicators were selected for health assessmentare grouped into the following three categories:

- ***Topographic indicators***: mean elevation and slope diversity
- ***Habitat indicators:*** proportion of forest cover, land cover diversity and mean productivity of the system
- ***Human disturbance indicators:*** mean human disturbance and distribution of disturbance points

Human Footprint data (Sanderson *et al.* 2002, source: http://sedac.ciesin.columbia.edu) represents the relative human influence in each terrestrial biome expressed as a percentage. This dataset is of 1-kilometer grid resolution and has been generated from nine global data layers covering human population pressure (population density), human land use and infrastructure (built-up areas, night time lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers). For the assessment at the scale of Pan-Himalaya, along with the forest cover and human footprint data, distribution models for two indicator species *viz*., snow leopard for alpine areas (>3800m) and Himalayan musk deer (subalpine areas 3000-3800m), drainage intensity, Protected Area (PA) coverage and Important Plant Areas (IPAs) were used as positive indicators and presence of Hydroelectric Power Projects in a grid was used as negative indicators. For each grid cell, the values of all the indicators were assessed and then standardized on a 0-1 scale using a minimum-maximum approach. The final index was generated using the topographic, land cover and the human disturbance indicators wherein each grid cell has a value ranging from 0-1; 0 indicating poor health and 1 indicating best health.

### *4.1.4 Assessment of Impacts - Climate Change Projections for IHR*

Climate projections for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) are made using the newly developed Representative Concentration Pathways (RCPs) under the Coupled Model Inter-comparison Project 5 (CMIP5). There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5 which represent pathways of radiative forcing. The current and future General Circulation Model (GCMs) projections from the Worldclim database were used to look at the probable climatic condition of IHR States in 2050. An ensemble of 17 GCMs was used.The results of predicted changes in mean annual temperature and precipitation are depicted here (Figure 4.2).

### *4.1.5 Ecosystem Health Index Assessment in a River Basin scale*

The Bhagirathi basin encompasses a wide range of elevation starting from 500m at subtropical zone to >5000m at trans-Himalayan cold deserts and accordingly represents a mosaic of several microclimatic regimes (Figure 4.3). For the uniform coverage and sampling of the area, the basin have been divided in to seven different sub-basins covering approximately 7000 $km^2$ area and different land cover and land use patterns including human habitation, agricultural land, large and small water reservoirs, rivers, streams and wetlands along subtropical, temperate, subalpine and alpine ecozones including arid zones of trans-Himalayan cold deserts. The vegetation in the basin ranges from subtropical forests (broadleaved and needle leaved), montane broadleaved and conifer forests, subalpine broadleaved and conifer forests, moist alpine meadows and scrub; and dry alpine meadow and scrubs.

### *4.1.6 Field work and data collection*

Rapid assessment of wildlife abundance and their habitats were done in Bhagirathi Valley as part of ongoing project under Task Force IV of National Mission for Sustaining the Himalayan Ecosystems. That deals with Assessment and Monitoring of Climate Change Effects on Wildlife Species and Habitats in the Indian Himalayan Region. The data generated based on secondary and primary effort was integrated in GIS domain to present the outcome in a spatially explicit form and also as tabulations in reports. Primary data on all sub-components were collected from representative strata. In addition, land use and protection status (National Park, Reserve Forest, or Community Forest) and human use levels (livestock grazing, forest produce collection, eco-tourism, pilgrimage and agriculture) were recorded from sampling stations. The sampling design follows hierarchical framework (sub-basins, rivers, grids, etc.) within the selected catchment such that the data on different components would be generated in same spatial/ecological sampling units for integration and appropriate inference.For the purpose of this study Bhagirathi basin was subdivided into 38 cells of 256 $km^2$ (16km x 16 km). Each of these cells were further subdivided into 4 km x 4 km grids (n=557) and sampling is ongoing in 3 to 4 such 4 km x 4 km grids within each 256 $km^2$cells (Figure 4.3).

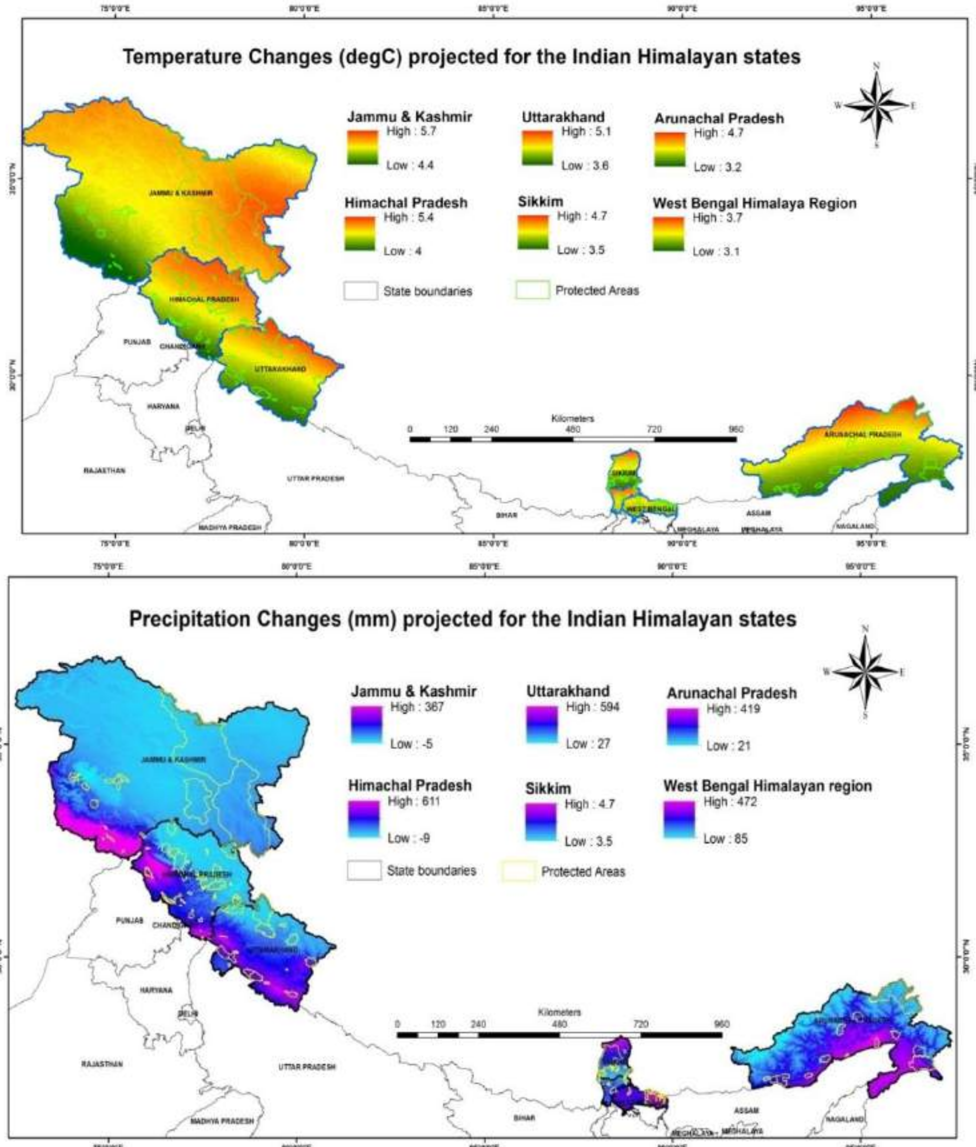
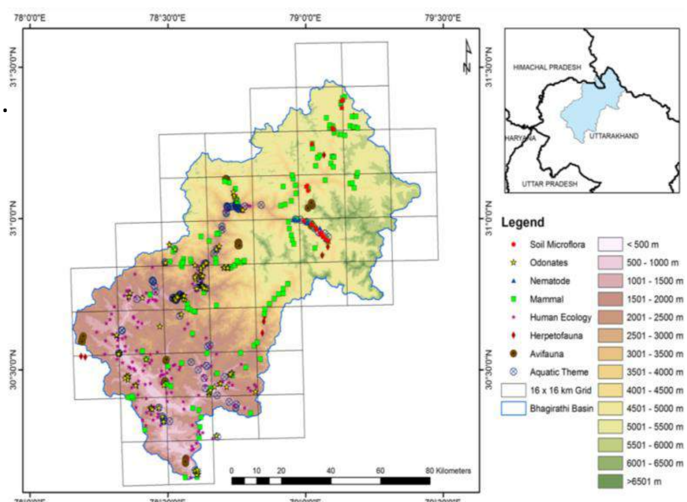



**Figure 4.2.Temperature and Precipitation projections for IHR States, the polygons outlined in yellow are denoting the Protected Areas**

For the Bhagirathi basin, standard methods were used to record the presence / absence and abundance of mammals and birds. For herpetofauna, nocturnal streams Visual Encounter Surveys (NVES) were used that involves three, one hour VES at each site. Diurnal VES (DVES) were conducted in each elevation zone for amphibians and reptiles by raking the leaf litter, turning logs and rocks, peeling bark and by opening fallen logs. In each belt, altitude, microhabitat features including soil pH, moisture, temperature and other habitat parameter were also measured using standard tools and methods. Well established sampling protocols for insect collection were adopted in different selected sampling plots. Odonates were sampled by visual encounter on transects with the methods including pitfall trapping, sweep netting, ground hand collection, aerial hand collection, vegetation beating, light traps and litter sampling. Dry specimens were starched, dried and preserves in insect boxes, while wet collections will be transferred to 70% alcohol. Identification was done on the basis of morphometric characters of various body parts.

Sampling was done in all orders of streams and seasonal sampling was conducted, (*i.e.* over 3 seasons- winter, summer and monsoon. Point samplings for fish were done at every 500m interval in the higher order streams (6$^{th}$ and higher) and at every 200m for lower order streams (5th and lower). Sampling for fish species was conducted at each 500 m reach; and fish diversity and abundance was assessed based on catch per unit effort (CPUE) and by underwater observation. Various fishing gears were used, (*i.e.*mono-filamentous gill nets, cast nets, drag nets and scoop nets). Apart from the present effort, recent assessment conducted by wildlife Institute of India (Rajvanshi *et al*. 2012) was also used to generate information on fish species richness per grid.

Structured questionnaires were used for identifying dependencies of local communities on key resources and ecosystem services. Select key indicator and parameters were used for quantifying existing dependencies



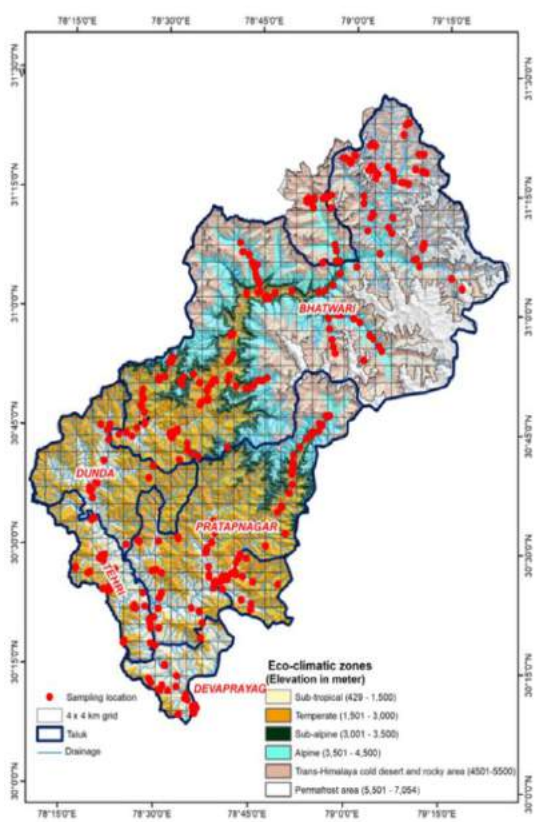




**Figure 4.3. Location map of Bhagirathi basin and sampling locations of mammals, galliformes, amphibians, fish and Odonates in different ecoclimatic zones and subbasins of Bhagirathi Basin, Uttarakhand**

### *4.1.7 Data Analysis and Assessment of Ecosystem Health*

The Bhagirathi basin was stratified into five eco-climatic zones, viz., Subtropical (elevation>1500m), Montane (1500-3000m), Subalpine (3000-3500m), Moist Alpine (3500-4500m) and Trans-Himalaya or cold desert (4500-5500m) as depicted in Figure 4.3. Entire area was divided into 4 x 4 km (16 $km^2$) grids for the ease of analysis and interpretation of the results. To assess the status of ecosystem health, grid specific values of anthropogenic, biological and topographic variables were quantified. Areas with >5500m elevation were excluded from the analysis as they fall within permafrost zone. The ecosystem health status for each grid was calculated by summing up the positive and negative scores.

Habitat status index included diversity of vegetation or wildlife habitats in each grid. Diverse array of Himalayan wildlife habitats were taken into consideration and represented in Table 4.3. The percentage area under each vegetation type within a grid was calculated using the unsupervised vegetation classification of the Bhagirathi basin. The extents of very dense and moderately dense forests within each grid were calculated using the database prepared by the Forest Survey of India. As a representative of the aquatic habitat status, intensity of drainage for each grid was calculated from the vector layer of streams and rivers of Bhagirathi basin.

To calculate the cumulative human influence in each grid, summation of normalized values of different anthropogenic variables such as cumulative impact of cattle-camps and villages, mean Human Influence Index, presence of Hydroelectric Power Projects, percentage area under agriculture, non -forest areas, scrubland and open forests were used (Table 4.3). Cumulative impact of cattle-camps and villages was calculated by summing the area under village influence and cattle-camps in a grid. All the cattle-camps within the Bhagirathi basin were digitized using ground location and satellite imagery (Source: Google Earth Pro 2017). Similarly, a 2 km buffer area was designated to each village location as area of influence. Total area under village and cattle-camp in a grid were calculated and ranked from low to high (1 to 5, 1= least area, 5= very large area).Presence of Hydroelectric Power Projects on major river Bhagirathi and its tributaries were extracted from the recent CWC database (National Register for Large Dams 2016), and from earlier EIA reports (Rajvanshi *et al.* 2012) and joined with the respective grids. Grids with existing and/or under-construction dams were coded as 1 and rest were coded as 0. Percentage of area under agriculture, non-forest areas, scrubland and open forests for each grid was calculated from the unsupervised vegetation classification of the study area and the information were cross checked with layers prepared by FSI. Change in the population density in a village was calculated for 805 villages from Census data 2001 and 2011. The average change in population density for the villages presented in a grid was also calculated.

Wildlife species richness in a grid was represented by the cumulative species richness of different taxonomic groups viz., mammals (large and medium non-volant mammals), birds (galliformes), herpetofauna (amphibians), fishes and insects (dragonfly and damselfly). Numbers of different species for each of these specific taxonomic groups were calculated for the sampled grids (Figure 4.3).Generalized Linear Models were used to predict the species richness of each taxonomic group for all the grids of the Bhagirathi Basin. Calculated species richness for a particular group in the sampled grids was used as response variables and along with anthropogenic and habitat parameters, topographic variables (Table 4.3) were also used as predictor variables. The resultant predicted species richness for each group was then summed up to represent the cumulative species richness for each grid.

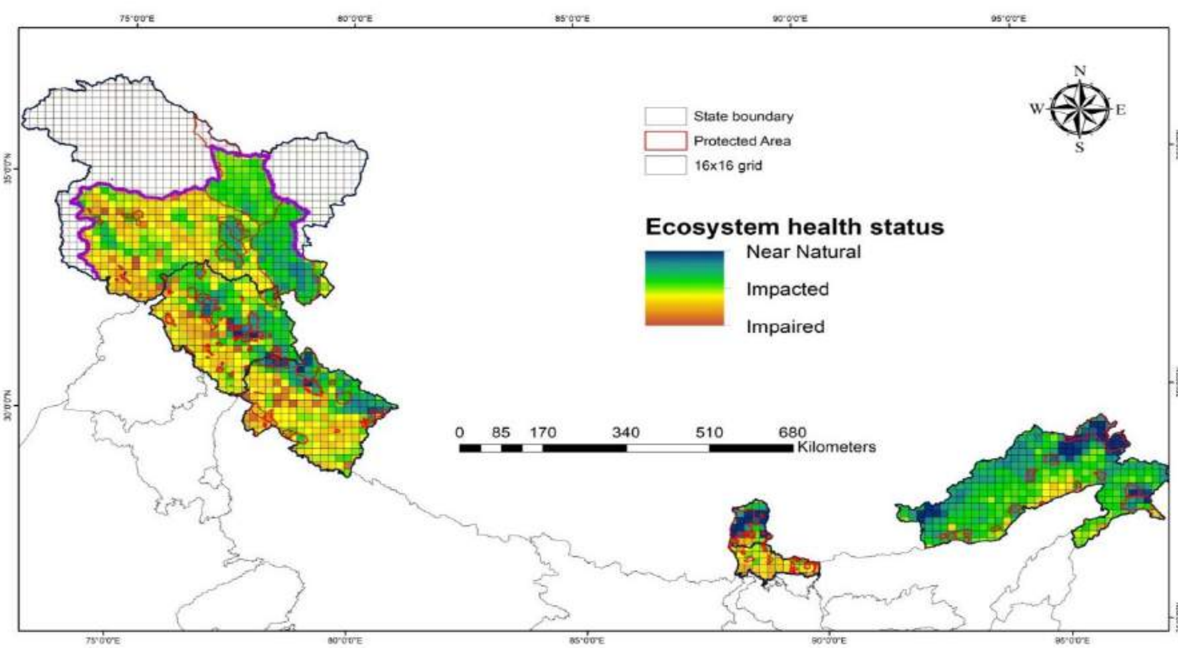
**Table 4.3. Different categories, parameters and their ranges as extracted for different grids in Bhagirathi Basin to assess the health status**

<table>
<tr><th colspan="2">Category</th><th>Parameters</th><th>Range</th></tr>
<tr><td rowspan="15">HabitatFactors</td><td rowspan="12">Vegetation types (%in a grid)</td><td>Subtropical Secondary scrub</td><td>0-85</td></tr>
<tr><td>Subtropical broadleaved</td><td>0-100</td></tr>
<tr><td>Subtropical Needle-leaved</td><td>0-100</td></tr>
<tr><td>Montane broadleaved</td><td>0-100</td></tr>
<tr><td>Montane Needle-leaved</td><td>0-100</td></tr>
<tr><td>Montane grassland</td><td>0-64</td></tr>
<tr><td>Subalpine Needle-leaved</td><td>0-100</td></tr>
<tr><td>Subalpine broadleaved deciduous</td><td>0-84</td></tr>
<tr><td>Subalpine broadleaved evergreen</td><td>0-67</td></tr>
<tr><td>Alpine moist meadow</td><td>0-99</td></tr>
<tr><td>Alpine moist scrub</td><td>0-85</td></tr>
<tr><td>Alpine desert steppe</td><td>0-89</td></tr>
<tr><td rowspan="2">Cover (%in a grid)</td><td>Moderately dense forest</td><td>0-100</td></tr>
<tr><td>Very dense forest</td><td>0-68</td></tr>
<tr><td>Water</td><td>Cumulative length of perennial water sources (km)</td><td>0-51.2</td></tr>
<tr><td colspan="2" rowspan="6">Anthropogenic factors</td><td>Mean Human Footprint Index (Sanderson et al. 2002)</td><td>0-40</td></tr>
<tr><td>Village and cattle-camp influence Index</td><td>1-5</td></tr>
<tr><td>Secondary Scrub(% in a grid)</td><td>0-76</td></tr>
<tr><td>Open forest (% in a grid)</td><td>0-22</td></tr>
<tr><td>Non forest (Habitation, rocky/scree, snow/glacier (% ingrid)</td><td>0-100</td></tr>
<tr><td>Presence of Hydroelectric Power Projects</td><td>0-1</td></tr>
<tr><td colspan="2" rowspan="3">Topographic factors</td><td>Mean Elevation (m) in a grid</td><td>719-6398</td></tr>
<tr><td>Mean Slope (°) in a grid</td><td>3-42</td></tr>
<tr><td>Major Aspect [E, SE, NE, Sas warmer (1) and SW, W,NW, Nas cooler (0)] in a grid</td><td>0-1</td></tr>
</table>

## 4.2 Key Findings on the status of Ecosystem Health

### *4.2.1 Overall status of ecosystem health in IHR*

Cumulative assessment of all the parameters at Pan-Himalayan scale reveals that majority (56%) grids in the IHR show moderate health. Nearly 27% grids exhibit excellent to near natural status. Few (17%) grids are highly impaired with poor ecosystem health. All such grids are located in the lower elevations (<1500 m). In both Western as well as in Eastern Himalaya, high altitude areas are providing the good to near natural habitats to the Himalayan wildlife. In Eastern Himalaya, areas outside PAs are also good to near natural in ecosystem health status, particularly in Sikkim and Arunachal Pradesh (Figure 4.4). Further, most of the area in Eastern Himalaya can be categorized under near natural and pristine condition whereas more area in Western Himalaya falls under poor (degraded) condition. The analysis also reveals that more than 48% grids in the Indian Trans-Himalaya, especially in Ladakh, Lahaul & Spiti and inner ranges of Uttarakhand fall under excellent health.



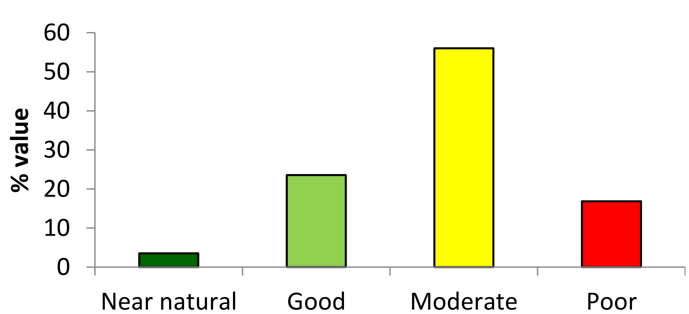




**Figure 4.4. Overall ecosystem health status in different 16x16 km grids of Indian Himalayan Region (the pink line is denoting Line of Control and Line of Actual Control, grids beyond this line are not considered for analysis)**

In the Greater Himalaya, only the high altitude (>3000m) PAs and their surrounding areas exhibit the characteristics of near natural status and rest of the areas are either moderate or impacted. All the grids near big Himalayan cities or towns exhibit impaired to degraded status.The ecosystem health of PAs in lower and mid-elevation zone are moderate to impacted with exception of Corbett National Park in Uttarakhand and two Wildlife Sanctuaries in the Siwalik ranges of Himachal Pradesh. Majority of the areas outside PA are degraded or impacted in the lower and mid elevation of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. However, there is a change in the pattern of ecosystem health in higher altitude and higher latitudinal areas. In fact, a nearly continuous belt of good to near natural ecosystem status is depicted for the subalpine and alpine areas of these three states.

As compared to the West Himalayan states, Sikkim and Arunachal Pradesh have >65% grids showing very good to near natural ecosystem health. Barring a few exceptions of major cities and congregations of Hydro-Electric Power Projects, no grid was depicted as impaired or highly impacted. The only exceptions are the two districts of Northern West Bengal, where only a few small PAs show moderate to good ecosystem health and rest of the area are either degraded or highly impacted. In the Eastern Himalaya, all high altitude PAs exhibit features of intact or near natural health and continuous distribution of such habitats.

### *4.2.2 Health Status Assessment of IHR in terms of Productivity*

The productivity status of IHR largely varies from near natural to good, while the productivity status is poor in restricted pockets. However, the poor productivity status shown in the higher areas must be taken with caution as it reflects status from the perspective of wildlife habitats, not a general productivity of the systems. Snow region is not good for wildlife habitat but would play a significant role in structuring the habitat condition below the permanent snow line. The state wise summary statistics are provided in Table 4.4. Of the Himalayan states, the states of Uttarakhand, Sikkim and Arunachal Pradesh contain large proportion of areas under the near natural productivity conditions (Figure 4.5) and these also reflect the protected area coverage, meaning that most of the Protected Areas represent very good or near natural productivity status. Interestingly, there are significant areas that are very good or near natural located outside this protected area network. This provides scopes for conservation management of the areas at the landscape scale. These areas (good and near natural areas) directly or indirectly reflect the ecosystem service values these may offer since the variables used in these analyses integrate structural and functional diversity of the system status.

**Table 4. 4: State wise health status of Indian Himalayan Region.**

| **States [n=27,901 grids]** | **Ecosystem Health Category (%Area)** | | | |
|---|---|---|---|---|
| | ***Poor*** | ***Moderate*** | ***Good*** | ***Near Natural*** |
| Jammu and Kashmir (*n=14,321)* | 9.94 | 67.49 | 20.85 | 1.72 |
| Himachal Pradesh (*n= 3,596)* | 11.60 | 38.10 | 37.54 | 12.76 |
| Uttarakhand (*n= 3,439)* | 2.12 | 13.67 | **55.63** | **28.58** |
| Sikkim (*n= 485)* | 9.28 | 36.49 | **31.96** | **22.27** |
| N. districts of West Bengal (*n= 653)* | 6.43 | 35.83 | 40.74 | 17.00 |
| Arunachal Pradesh (*n= 5,407)* | 1.07 | 12.24 | **47.48** | **39.21** |

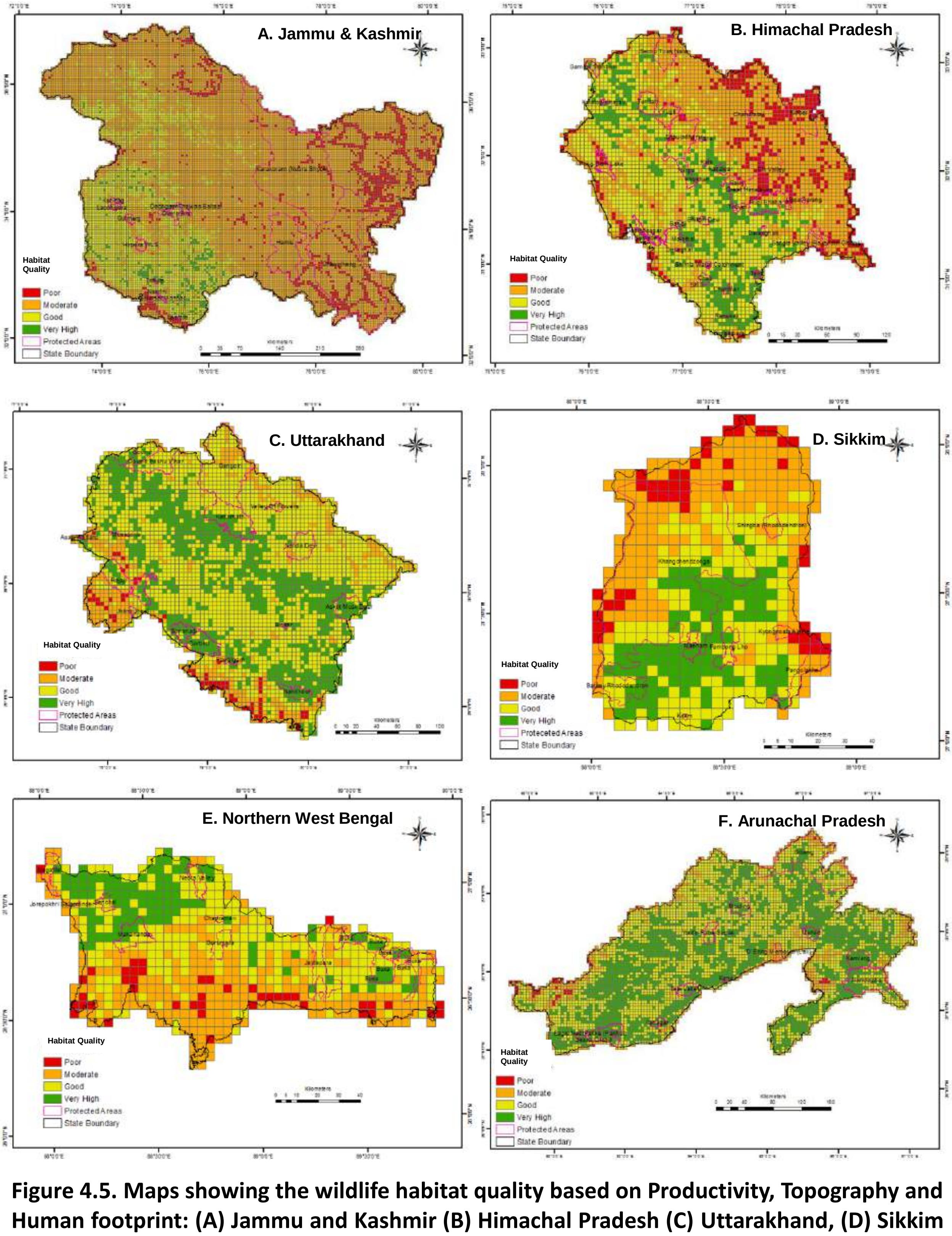



**Figure 4.5. Maps showing the wildlife habitat quality based on Productivity, Topography and Human footprint: (A) Jammu and Kashmir (B) Himachal Pradesh (C) Uttarakhand, (D) Sikkim (E) Northern districts of West Bengal (F) Arunachal Pradesh**

### *4.2.3 Status of Ecosystem Health in Bhagirathi Basin*

Outputs of Generalized Linear Models depicted species richness for different taxa in different eco-climatic zones of Bhagirathi basin. Key parameters influencing wildlife habitats and species richness in the basin are given in Table 4.5. Mammal species richness was negatively correlated with intensity of agriculture (less percentage area of croplands), degree of slope, proximity to human habitation and positively correlated with higher proportion of montane grasslands and/or alpine vegetation in a grid. Both amphibian and Odonate species richness was positively related with drainage intensity and warmer aspects and negatively correlated with elevation (Table 4.5). Fish species richness was also positively related with drainage intensity (Table 4.5). Mammal species richness was high in temperate and alpine zones whereas fish, Odonate and amphibian species richness was high in lower elevation eco-climatic zones (Figure 4.6). Cumulative species richness was relatively higher in mid-montane, sub-tropical and alpine zones, whereas trans-Himalayan dry alpine areas were less diverse in terms of cumulative species richness as no fish and amphibian species were found there.Status of habitat indexwas calculated for each of the above-mentioned eco-climatic zones of Bhagirathi basin. Percentages of grids with high to very high habitat heterogeneity were mostly present in temperate and sub-alpine zones (Figure 4.7). Trans-Himalayan (cold arid region) showed least habitat heterogeneity. Cumulative human influence was highest in the grids located in sub-tropical and temperate zones (Figure 4.8). Most of the temperate zone was impacted moderately. Spatial pattern of cumulative human influence is depicted in Figure 4.9a, where all the village locations, cattle-camps (Outside Gangotri National Park), major roads, existing Hydro-electric Power Projects have been overlaid. Changes in human population density during 2001 to 2011within all the grids of Bhagirathi basin (Figure 4.9b) reveals that Devaprayag and Pratapnagar have faced more decline, whereas grids representing Ghansali, Tehri and Uttarkashi show very high growth in human population.

Based on cumulative impacts of habitat heterogeneity, species richness and human influence, overall status of biodiversity and habitat in Bhagirathi Basin is depicted in Figure 4.9c. It reveals that subalpine and alpine areas in upper Bhilangana and upper Balganga areas are near natural and areas near Tehri and Devprayag are in relatively poor condition (Figure 4.9d). Majority of the subalpine areas exhibit the characteristics of‘near natural’ or ‘very good’ health whereas majority of the grids present in temperate zones were assigned as moderate in terms of biodiversity and habitat status. Percentage of grids with moderate health was high among all the grids in the basin followed by poor and very poor. However, as many as 31 (6%) grids still represent near natural condition (Figure 4.9e).

**Table 4.5. Significant parameters to explain species richness for different taxonomic groups in Bhagirathi Basin**

| Group | Parameters | β estimates | Std. Error | Wald Chi-Square (df=1) | Significance level (0.05) |
|---|---|---|---|---|---|
| **Mammals** | Subtropical Broadleaved | -13.864 | 4.11 | 11.35 | 0.001 |
| | Subtropical secondary scrub | -4.084 | 1.07 | 14.321 | 0 |
| | Subtropical Needle-leaved | -2.923 | 0.53 | 30.312 | 0 |
| | Montane broadleaved | -2.408 | 0.68 | 12.462 | 0 |
| | MontaneNeedle-leaved | -1.794 | 0.59 | 9.069 | 0.003 |
| | Montane grassland | 1.112 | 0.30 | 13.577 | 0 |
| | Subalpine Needle-leaved | -2.464 | 0.64 | 14.604 | 0 |
| | Alpine desert steppe | 1.858 | 0.32 | 33.653 | 0 |
| | Moderately dense forest | -2.054 | 0.34 | 36.138 | 0 |
| | Cropland | -5.221 | 0.50 | 108.769 | 0 |
| | Elevation | -12.064 | 0.89 | 180.751 | 0 |
| | Slope | 1.401 | 0.47 | 8.547 | 0.003 |
| **Galliformes** | Alpine desert steppe | 2.38 | 1.12 | 4.457 | 0.035 |
| | Slope | 6.237 | 1.78 | 12.24 | 0 |
| **Amphibians** | Cumulative drainage length | 2.491 | 0.97 | 6.582 | 0.01 |
| | Moderately dense forest | 1.71 | 0.74 | 5.308 | 0.021 |
| | Very dense forest | 1.841 | 0.77 | 5.598 | 0.018 |
| | Slope | 9.875 | 1.81 | 29.567 | 0 |
| | Elevation | -5.559 | 1.41 | 15.401 | 0 |
| | Cooler Aspect | -0.647 | 0.29 | 4.702 | 0.03 |
| **Fish** | Cumulative drainage length | 2.241 | 0.79 | 7.97 | 0.005 |
| | Open forest | 3.847 | 0.89 | 18.48 | 0 |
| | Moderately dense forest | 2.949 | 1.02 | 8.297 | 0.004 |
| | Slope | 5.126 | 1.82 | 7.862 | 0.005 |
| | Elevation | -10.48 | 2.12 | 24.262 | 0 |
| **Odonates** | Cumulative drainage length | 1.745 | 0.32 | 29.49 | 0 |
| | Moderately dense forest | -1.921 | 0.36 | 28.093 | 0 |
| | Slope | 1.621 | 0.62 | 6.786 | 0.009 |
| | Elevation | -2.725 | 0.34 | 63.496 | 0 |
| | Cooler Aspect | -0.67 | 0.12 | 29.13 | 0 |

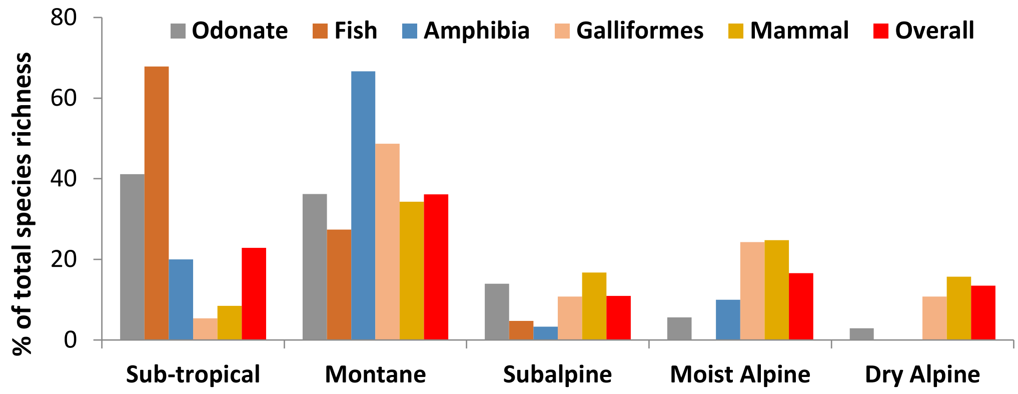



**Figure 4.6.Species richness (%) in total and for different taxonomic groups in different eco-climatic zones of Bhagirathi Basin**

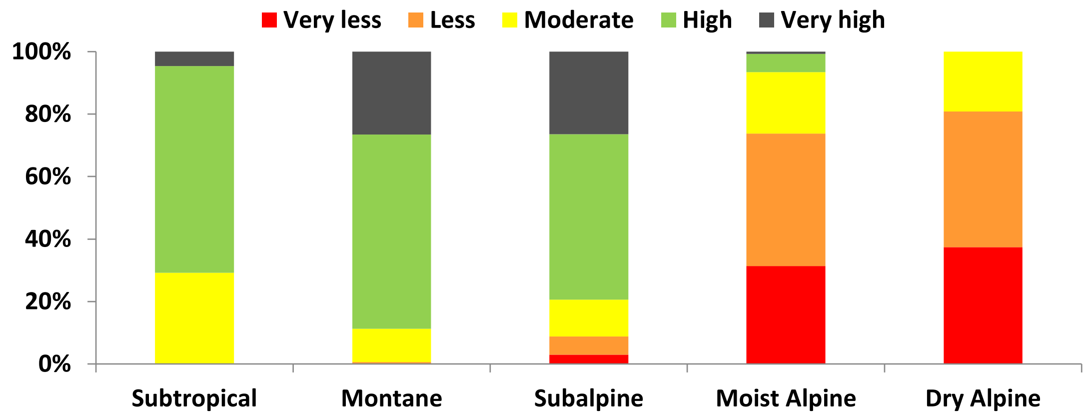



**Figure 4.7.Status of habitat (%) in different eco-climatic zones of Bhagirathi Basin**

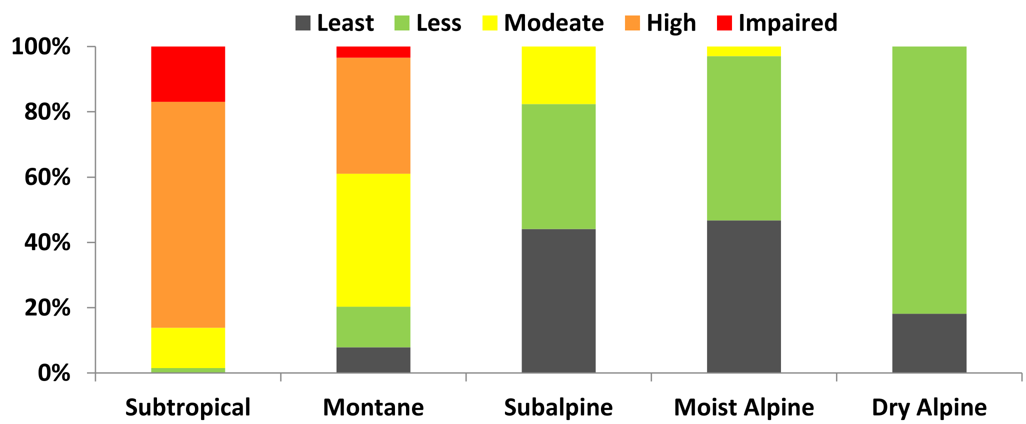



**Figure 4.8.Status of cumulative human influence (%) in different eco-climatic zones of Bhagirathi Basin**

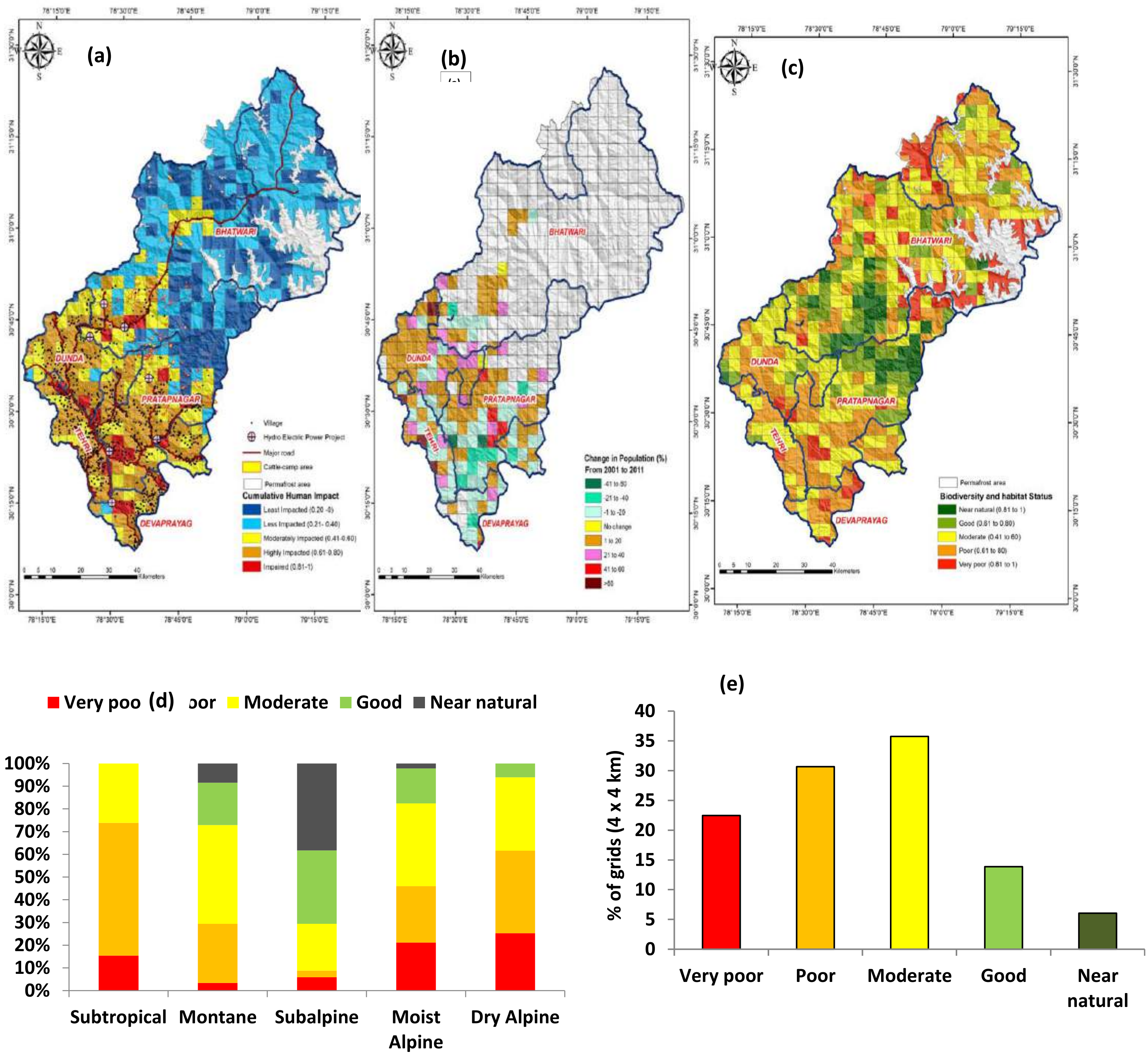



**Figure 4.9. (a) Cumulative human impact,(b) Percentage change in Population density, (c) Overall biodiversity and habitat status in different 4 x 4 km grids, (d) Status of biodiversity and habitat (%) in different eco-climatic zones, (e) Overall status of biodiversity and habitat (%) of Bhagirathi Basin, Uttarakhand**

### *4.2.4 Status of Aquatic Ecosystem*

**Status of riverine habitat: Acase study from Bhagirathi Valley**

The Bhagirathi basin comprises a total catchment area of about 8846.64 km$^2$ and the river rises from the Gangotri glacier at Gomukh at an elevation of about 3900m. The river then flows from its source for 205 km, meets several tributaries before meeting the Alaknanda river at Devprayag (475m asl). A total of 32 hydropower projects both large (>25 MW) and small (<25 MW and >1MW) with a total installed capacity 4871 MW have been planned within this basin. There are 9 commissioned projects, 4 projects are under-construction and 19 are proposed to be constructed in near future. Though, several studies have been conducted on aquatic biodiversity of Bhagirathi and its tributaries (Sharma, 1983; 1984; 1985; 1986; 2003, Nautiyal, 2007, Sarkar et al. 2011), impacts of anthropogenic pressures on the aquatic biodiversity is unavailable for the basin. A total of 49 species of fishes are known to occur in the Bhagirathi river (present study and Rajvanshi et al., 2012). The river and tributaries are mostly dominated by Cyprinids followed by Balitoridae and Sisoridae. Major species in Bhagirathi include snow trout (*Schizothorax* spp.), the mahseer (*Torputitora*), the lesser barils (*Barilius* spp.), the hillstream loaches (*Nemacheilus* spp.) and the Sisorid torrent cat fishes (*Glyptothorax* spp.). No species has so far been reported above 2400-3000 m. The current ecological conditions and threats are summarized in Table 4.6.

### *4.2.5 Status of high altitude wetlands: A Case study from Eastern Ladakh*

The Indian trans-Himalaya harbours some of the most spectacular and biologically rich wetlands in the world. These wetlands provide breeding habitats to several resident and migratory water birds. Some of the prominent trans-Himalayan wetlands are located in Eastern Ladakh, Zanskar, Spiti, northern parts of Uttarakhand and Sikkim plateau. Bio-physical features of some of these wetlands have been well documented but most of them are poorly known. North Sikkim has small breeding population of the ruddy shelduck (*Tadorana ferruginea*) and black necked crane *(Grus nigricollis)* (Ganguli-Lachungpa 1998). In Ladakh, decline has observed with respect to the breeding birds particularly Bar-headed Goose *(Anser indicus)*, Brown headed Gull *(Chroicocephalus brunnicephalus)* and Ruddy Shelduck (Hussain *et al.* 2008; Namgail *et al.* 2009). In addition, decline has been observed in the breeding success of Black-necked Crane in Ladakh despite increase in population since 1990s.

The trans-Himalayan wetlands are under immense pressure due to increasing anthropogenic pressures and also vulnerable to climate change (Patel *et al.* 2009). A limnological study by Hussain *et al.* (2008) revealed that water quality of Tso Moriri lake in eastern Ladakh has changed drastically compared to the earlier measurements done by Hutchinson (1937). These changes are largely attributed to anthropogenic deposition of Ammonium-N and Nitrate-N by to the streams feeding this lake. Predation and flooding are two well established reasons for the breeding failure in recent study.

### Table 4.6. Status of the fish diversity and current ecological conditions of Bhagirathi river basin

* listed as endangered and vulnerable categories as per NBFGR(2009

| River stretch | Fish diversity | Indicator/Key species | Habitat specialist/ threatened species* | Current ecological conditions ↑Fair conditions ↓Poor conditions |
|---|---|---|---|---|
| **Bhagirathi I (Areas above Bhagirathi- Jadh ganga confluence)** | No fish zone | Primary producers and aquaticmeiofauna | - | This oligotrophic basin has perennial, cooler, cleaner water. Moderate threat due to road, cattle camps and pilgrims ↑ |
| **Bhagirathi II (Bharongati to Asi ganga)** | 19 | Golden mahseer(*Tor putitora*), Snow trout *Schizothoraxrichardsonii* | 11/4 | The river serves as migratory route for golden mahseer and snow trout. The upward movement has been stopped due to existing dam ↓ |
| **Asiganga (Asiganga valley)** | 3 | Snow trout | 2/1 | A major breeding ground for snow trout. Oligotrophic to mesotrophic conditions with clean and cooler water. ↑ |
| **Bhagirathi III (Uttarkashi to confluence of Bhilangana with Bhaghirathi):** | 43 | Golden mahseer Stone suckers *(Garragotylagotyla,)* Hill stream catfish *Glyptothoraxtelchitta* | 27/12 | A relatively disturbed sub-basin. Isolated population of Golden mahseer in the upstream of Tehri Dam use Bhilangana river as the major breeding ground. Introduced exotic species in Tehri Dam are abundant in the reservoir and the downstream areas. ↓ |
| **Bhagirathi IV (From Bhagirathi-Bhilangana confluence to Devprayag)** | 48 | Endemic hill stream catfish, *Glyptothoraxalaknandi,* Golden mahseer | 29 /12 | Fragmented population of migratory species due to existing power projects in the area. Anthropogenic pressures and many developmental activities in this sub-basin are high. ↓ |
| **Bhilangana (Bhilangana valley)** | 43 | Golden mahseer Black mahseer (*Tor chilinoides*), Snow trout | 27/11 | The lower stretch of this river basin is one of the important breeding habitats for migratory species like snow trout and mahseer. Currently, the populations of these species are fragmented due to existing dams. ↓ |
| **Balganga sub-basin (Balganga valley)** | 38 | Golden mahseer Black mahseer, Snow trout | 24/11 | This river is one of the critically important habitats for mahseers and snow trouts which occurs in Tehri Dam and associated rivers. Many migratory species congregate along the rivers for breeding especially after the monsoon. ↑ |

Free ranging dogs mainly attributed to predation, which requires immediate management intervention near breeding sites. Nest destruction due to flood has been observed in glacier-fed lakes.Agriculture, willow plantation, development of pastureland and defence instalments on wetlands has changed landuse pattern on micro scale (Humbert-Droz 2017). About, 2 sq. km depletion in the water body of Tso Morriri has observed over a decade (Gupta & Shukla 2016). In Tso Moriri basin, however, livestock number has decreased over the years, 8 % decline in sheep and 30% decline has observed in goat population in between year 2013 and 2017 (J&K Husbandry Dept. data). Since young generation is out migrating for better lifestyle and livelihood options in recent past (Goodall 2004; Bashin 2012).

Over the last decade, unregulated tourism has increased manifold and mainly concentrated in proximity to wetlands, which has led to increase in the human pressure on wetland and associated flora and fauna. Therefore, long term ecological monitoring of Trans-Himalayan wetlands is need of hour. Some of the wetlands recommended for intensive monitoring are Tso Moriri, TsoKar (Ladakh), Chandra Tal (Himachal Pradesh), Sitaxi Lake and Parvati Tal (Uttarakhand) and Khecheopalri and Lhonak Lake (Sikkim). Vegetation communities, migratory waterbirds (nesting sites and migration pattern), human use (tourism and pastoralist pressure on wetlands), landuse change and water chemistry may be considered for monitoring on micro level to assess the health of these wetlands.

**Figure 4.10. Lake TsoMoriri (a Ramsar site) in Ladakh is highly impacted by anthropogenic activities**

## 4.3 General Trends in the Ecosystem Health status

### *4.3.1 Status of wildlife habitat and productivity trends across IHR*

Barring a few well managed PAs, the subtropical belt in the Western Himalaya exhibits poor state of ecosystem health. This could be attributed to concentration of human populations and sprawling urban growth and spread of invasive alien species in recent decades. The high altitude areas of both west and east Himalaya showed good to very good status of ecological health. However, information on human influence in these areas is scanty in the absence of reliable data on the abundance of domestic livestock, hunting pressure and annual extraction of non-wood forest products (NWFP) including medicinal and aromatic plants from different eco-climatic zones.At the crude scale, all grids with high densities of human populations also showed decline in productivity, and degradation of forested habitats. Alpine moist and arid habitats (above 3800m), though exhibit low primary productivity, are generally in moderate to good health barring a few pockets where there has been increased influx of migratory livestock grazing.

#### *4.3.2 Trends in Bhagirathi Basin*

Overall ecosystem health in the Bhagirathi basin in terms of faunal diversity and wildlife habitat quality is moderate. 29% montane forests, 9% sub-alpine and 53% alpine habitat in Bhagirathi basin can be categorized under poor or highly impacted. Nearly 18% grids show good to very good ecosystem health in terms of faunal richness and habitat diversity. Outmigration of rural populations to sub-urban and urban areas in this basin is likely to shift the anthropogenic pressures on forested habitats in future. Regular monitoring of ecosystem health in and around such villages would be desirable.

***Health of Forest Ecosystem:*** The status of mid-montane and subalpine forests is assessed to be moderate to good.Recent records of few charismatic but threatened mammalian taxa, viz.,Tiger (*Pantheratigris*), Himalayan brown bear (*Ursusarctosisabellinus*), and Asiatic wild dog (*Cuonalpinus*)in the high altitude forests of Bhagirathi basin by WII team and occurrence of other species especially Himalayan musk deer (*Moschus chrysogaster*), Asiatic black bear (*Ursusthibetanus*) and sambar (*Rusa unicolor*) in the high altitude forests of in several pockets of Bhagirathi basin indicates that these habitat are still healthy and congenial to support these flagship species. Lower vertebrates such as amphibians, fishes and invertebrates (Odonates) exhibit poorer habitat conditions as these taxa are more sensitive to anthropogenic as well as climatic drivers. Responses of these species to these drivers within a few representative habitats need to be monitored over time.

***Health of Dry Alpine Ecosystem:*** Though the index depicted moderate to poor status to the trans-Himalayan dry zone, these areas are home of many of the threatened mammals such as snow leopard (*Pantherauncia*), Tibetan wolf (*Canis lupus*) and Tibetan Argali (*Ovisammon*). Dry alpine areas of Bhagirathi basin hold two partridges (Chukar and snow partridge), Himalayan snowcock and (occasional presence) Himalayan monal as Galliformes. Though, this area does not have any permanent human habitation, heavy influx of migratory Gaddi herders from Himachal Pradesh during June to October in Nelang valley and presence of several packs of feral dogs are major causes of concern.Stringent management action is necessary to maintain the current status of the ecosystem in this fragile area, in terms of curbing the populations of stray dogs and protecting the alpine peatlands and marsh meadows.

***Health of alpine moist meadows:*** Most of the upper areas of Bhagirathi basin are protected as the Gangotri National Park. Hence, such areas are free from livestock grazing and collection medicinal plants. However, there is an increasing pressure in the form of religious tourism in some parts of GNP and demand for infrastructure development. The alpine and subalpine areas outside the National Park, especially Kandara, Dayara, Gidara, Kushkalyani and Kheratal meadows are heavily grazed by livestock during summer-monsoon.Some of these meadows are also very rich in high value medicinal plants.

***Health of riverine ecosystem***: The massive network of hydroelectric power plants across the Bhagirathi river basin is a grave threat to the river and riverine ecosystem. In view of constructed and under construction hydroelectric projects the major loss can be considered in Bhagirathi III and IV followed by Balganga and Bhilangana. There are a minimum of 12 species of migrant fishes found in the Bhagirathi basin, which include threatened species like mahseer and snow trout that are long distance migrants. Based on their assemblage and dominance the basin can be categorized into 'mahseer zone' and 'snow trout zone'. No fish was found on the higher altitudes i.e. 1600 MSL and above and can be categorized as 'No fish zone'. Below the 'no fish zone', is the snow trout zone where water temperature is always low but in the mahseer zone,which falls in the lower altitude rivers and streams, water is relatively warm. The basin also harbours some of the well-established population of exotic species like brown trout (*Salmo truttafario*) in higher altitudes and common carp (*Cyprinus carpio*) in lower region. In view of river health monitoring different zones can be monitored based on different criteria for e.g. presence of rare and endangered aquatic biota, presence of endemic species, diversity of aquatic habitats, presence of protected areas, ecological requirements and health of indicator species. As per the present observations the life history traits and ecological requirements of snow trout and golden mahseer can be assessed for river health monitoring in their respective zones.

## 4.4 Limitations of the assessment

One of the most important parameter of ecosystem health assessment is the availability of the historical/past data on the responsive indicators. For the Himalayan ecosystem such trends are quite rare and available sporadically for a few categories of indicators. Availability of long term datasets on physical factor such as temperature, rainfall, snowcover and riverine/aquatic parameters are very useful in assessing trends in the quality and health of the mountain ecosystems and inter-operability of these datasets is still lacking. The aspect of wildlife disease is still not mainstreamed in the IHR. Spatial distribution of these wildlife disease outbreaks can strengthen the analytical procedure in future.

In case of the productivity status analysis, the higher areas may appear to be under represented, and this is largely because the analyses captures habitat productivity of all wildlife diversity (particularly emphasizing on forest productivity) not just one or two taxonomic groups which may be ecologically significant and representative of the system. This is one of the demerits of the large scale analyses but can be addressed with taxonomic level analyses and this requires field level information to support the results. At the Pan-Himalayan scale, emphasis on presence of Protected Area coverage in a grid has yielded realistic results in sub-tropical, montane and alpine eco-regions of Greater Himalaya. However, this scoring procedure has not yielded meaningful result in trans-Himalayan areas where protection from anthropogenic interference does not hold much relevance due to nil or very low anthropogenic presence.

## 4.5 Future Directions

***Information requirements:*** Annual monitoring of the health status in Pan Himalayan scale will only be effective if the annual change in human footprint can be assessed and indexed. In accumulation to that, the change in forest cover and change in land-cover categories can also be indexed using GIS tools. Parameters for both terrestrial and aquatic system, which can be monitored for such initiatives in future, are listed in Annexure I (for the entire Himalayan ecosystem) and Annexure II (detailed description for aquatic ecosystem parameters). Baseline information on the climatic variables such as temperature and precipitation is available at a course scale, however, primary information in different eco-climatic zones throughout the Himalayan range is still lacking. Once such database on temperature and precipitation trends is available for the entire range, prediction on macroclimatic changes in different emission scenarios will be more robust and specific.

***Impact of climate change:*** Preparation of robust species distribution models in different future climatic scenarios based on the present scenario of species presence locations can serve as an essential tool for policy formulation. From the current analysis, it is clear that in future temperature of the best ecosystem health areas in the Himalaya will raise manifold. The impact of this temperature rise on the key faunal elements can be assessed in future using species distribution modeling. Impact of climate change on the current ecosystem health of Bhagirathi basin will be negative both in terms of biodiversity and habitat status. Increase in temperature and alteration in precipitation pattern and intensity will definitely hamper the delicate balance of upper elevation alpine ecosystem. Some symptoms observed during the present study such as the persistent presence of Rhesus macaque (*Macacamulatta*) in the very high elevation (4500m) areas of trans-Himalaya during warmer season (April to October), presence of pathogens (*Arceuthobium minutissimum*) in the subalpine needle-leaved forest and outbreak of Keratoconjunctivities in the blue sheep population in alpine areas of Gangotri National Park are indicating towards alteration in the current situation. However, the future change in lower areas, where biodiversity and habitat status is a function of both climatic and anthropogenic factors can be predicted only after much detailed long term comparative study in future.

***Long term monitoring:*** Long term monitoring of some grids depicted as good to best in ecological conditions in Bhagirathi basin and the river stretches identified as best habitats for indicator species (**Figure 4.11**) can help to generate information on change in ecosystem health in an annual basis. Periodic assessment of the ecosystem health of these near natural habitats within potential distribution range of eco-climatic zone specific indicator species (n=15, 5 species each from mammals, birds and herpetofauna) can elucidate the trend of terrestrial habitat health status at different scale. Similar rigorous field information generation is currently going on in Beas Basin of Himachal Pradesh and Teesta Basin of Sikkim. Long term monitoring of near natural grids in different eco-climatic zones of these three biogeographic zones will provide necessary insight on monitoring strategy of the Himalayan health status on an annual basis.

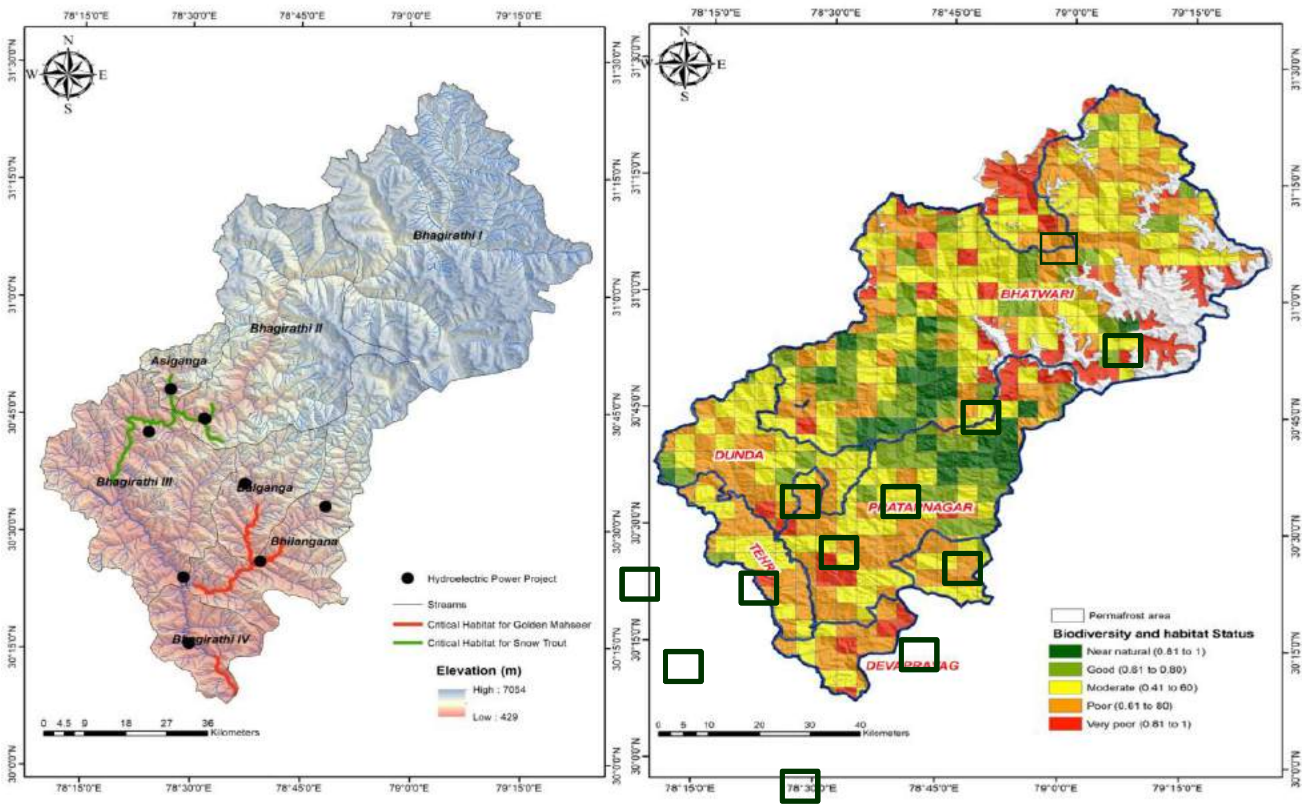



**Figure 4.11.Long term monitoring areas selected for aquatic and terrestrial ecosystems for annual ecosystem health assessment in Bhagirathi Basin, Uttarakhand**

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## *Annexure I*

**Indicators proposed/used for the assessment of terrestrial ecosystem health at various scales in the IHR**

| | Scale and Indicators | | | |
|---|---|---|---|---|
| | **Pan-Himalaya** | **State** | **River Basin** | **Specific Ecosystems within pilot sites** |
| **Habitat Factors (Biotic)** | Change in Forest Cover<br>Change in Productivity<br>Large distribution range indicator species | Change in forest cover, productivity<br>Corridor/ Connectivity<br>Patchiness<br>Range of Rare, Endangered or Threatened species of the State (Red Panda, Red Deer, Musk Deer, Galliformes, Fishes | Forest Cover change<br>Vegetation Type cover change<br>Extent of weeds/IAPS<br>Change in extent of meadows<br>Connectivity ofhabitats<br>Patchiness<br>Richness of indicator group of species (mammal, bird, fishes, insects)<br>Abundance of Indicator group of species (mammal, bird, fishes, insects) | **Alpine ecosystem (moist and dry)**<br>Ratio of palatable/unpalatable species<br>Change in extent of meadows<br>Change in cover of different types of meadows**Forest Ecosystem**<br>Extent of invasive species<br>Extent of natural vegetation cover<br>Abundance of indicator species of different taxonomic groups |
| **Anthropogenic factors** | Human Influence Index<br>Protected Area Coverage<br>Extent of land conversion due to developmental projects | Human Influence Index<br>Change in coverage of Protected Areas<br>Change in protection level<br>Extent of land conversion due to developmental projects | Density of villages<br>Coverage of roads<br>Density of livestock camps<br>Expansion of forest gaps<br>Change in PA coverage<br>Change in protection status<br>Land coversion due to developmental (Power ) Projects | **Alpine ecosystem**<br>Livestock Impact Units<br>Tourism Impact Units<br>**Forest Ecosystem**<br>Density of livestock camps<br>Expansion of forest gaps<br>Density of villages<br>Coverage of roads<br>Change in % area under PA coverage<br>Change in population<br>Dependency on forest for resource extraction (% or biomass extraction)<br>Cattle and Livestock density<br>Presence of developmental (Power ) Projects |
| **Physical Factors** | Change inpatterns of temperature, precipitation<br>Changes in aquatic health parameters | Change inpatterns of temperature, precipitation<br>Mean elevation Slope diversity. Changes in aquatic health parameters | Change inpatterns of temperature, precipitation, humidity<br>Changes in aquatic health parameters | Change inpatterns of temperature, precipitation, humidity<br>Status of soil physical parameter (Nutrients, pH, moisture)<br>Changes in aquatic health parameters |

## *Annexure II*

### Aquatic ecosystems health indicators and methods of assessment

| | **Criteria and indicators** | **Methods of assessment** | **Thresholds** | | |
|---|---|---|---|---|---|
| | | | **Poor (Score: 1)** | **Fair (Score: 2)** | **Good (Score: 3)** |
| 1. | **HYDROLOGICAL INTEGRITY** | | | | |
| **1.1** | Width (rivers and streams) and size (wetland) | Field survey, remote sensing maps and GIS | Reduction in Width (river, streams), area (wetland) in last 10 Years | No change in the width/area in last 10 years | No change in width/area in last 20 years |
| **1.2** | Adjacent land use | Assessment of land use through village survey, remote sensing and GIS. | Urban or rural land use within 200 m of the boundary.**Or**<br><br>More than 50% of the land within 100 m of the boundary. | Rural land use outside 200 m<br><br>(or)<br><br>Urban land use outside 500 m of the boundary. | Rural land use with buffer of around 500 m of the boundary with negligible human activities. |
| **1.3** | Connectivity | Assessment of land use through village survey, remote sensing maps and GIS | Connectivity with other wetland/river, forest and grassland disrupted wholly. **Or**<br><br>Linear connectivity between upstream and downstream disturbed by barriers without MEF and Fish passes | Connectivity exists only in rainy season otherwise no connectivity.**Or**<br><br>Linear connectivity between upstream and downstream disturbed by barriers with MEF and Fish passes | Connectivity with other wetland/river, forest and grassland exist.**Or**<br><br>Linear connectivity between upstream and downstream of a river or stream undisturbed by barriers |
| **1.4** | Dykes and roads in or along the river, stream or wetland | Field observations and secondary data | Dykes, roads and railway track without any culvert or bridge obstructing free water flow. | Dykes, roads and railway track with adequate culvert or bridge crisscross | No dykes and roads |
| **1.5** | Siltation | Bathymetry | Major silt deposition | Minor silt deposition. | Negligible silt deposits. |
| **1.6** | Water withdrawal in orsurrounding upland | Field observations and secondary data | Withdrawal of water increased expansion in last 10 years. | Expansion of these activities in last 10 years. | Decline of these activities in last 10 years. |
| **1.7** | Environmental water availability | Monitoring of flow, water depth and wet area | Major portion of the wetland/river has zero flow. | Some portion of the wetland/River has zero flow. | Flow regime is intact. |
| **1.8** | Water depth | Depth gauge, sonar | Substantial change in flow regime or water depth. | Moderate change in flow regime or water depth. | Negligible change in flow regime or water depth. |

| | | | | | |
|---|---|---|---|---|---|
| 2. | **WATER QUALITY** | | | | |
| **2.1** | Visible water pollution | Site level inspection based on observer's perception. | CPCB Water Quality Criteria Class B | CPCB Water Quality Criteria Class B | CPCB Water Quality Criteria Class A |
| **2.2** | Visible algal bloom | Fluorometerand site level inspection | Accumulation of microalgae layer>1 cm thick is evident. | Accumulation of microalgae layer 0.1 to 1 cm thick is evident. | Accumulation of microalgae layer<0.1 cm thick is evident. |
| **2.3** | Extent of pesticide, herbicide, inorganic manure used | Survey of agricultural land surrounding wetlands and rivers. Laboratory analysis | Pesticide use in more than 50% of the catchment area. | No pesticide use in 75% of catchment area. | Negligible pesticide used in the catchment. |
| **2.4** | Temperature | Thermometer | Increase in temperature due to human induced factors | Negligible increase in temperature | Stable |
| **2.5** | pH, Transparency, turbidity, DO, COD, TDS, Nitrogen, Nitrite and Phosphorus | Hand held multi-parameters, Sepctrophotometric method | Less than 90% of Indian Standard for drinking water specification – (IS10500:1991) | More than 90% of Indian Standard for drinking water specification (IS 10500: 991) | As per the Indian Standard for drinking water specification (IS 10500: 1991). |
| **2.6** | Presence of pathogens (Total coliform, faecal coliform, *E.coli*) | MPN or MF methods approved CPCB. | Total Coliforms Organism MPN/100 ml >500 | Total Coliforms Organism MPN/100 ml >500 | Total Coliforms Organism MPN/100ml shall be 500 or less |
| 3. | **BIOTIC COMMUNITY – FLORA** | | | | |
| **3.1** | Free floating invasive species (% wetland area) | Ocular estimation | More than half of the area is colonized by invasivespecies | Some weed incursion into resulting from edge colonization | No invasive present in the wetland |
| **3.2** | Rooted invasive species (% wetland area) | Plot method (1 m x 1 m) | More than 50% of the area covered with weeds or invasive plants | Some weed incursion into resulting from edge colonization | Less than 5% of the wetland and its boundary is affected by weeds |
| **3.3** | % area covered with vegetation | Ocular estimation | >70% area covered with vegetation | >50% area covered with vegetation. | >30% area covered with vegetation |
| **3.4** | % shoreline area covered with vegetation | Ocular estimation | No vegetation or 50% of shore vegetation degraded. | Less than 25% shore vegetation degraded. | Intact and no degradation of shore vegetation. |
| **3.5** | Number of native riparian | Floristic survey | Reduction in number of native species by 50% or | Reduction in number of native species by | Number of native species is stable or negligible |

| | | | | | |
|---|---|---|---|---|---|
| | plant species | | more in last 10 years | less than 50% in last 10 years | reduction. |
| 4. | **BIOTIC COMMUNITY – FAUNA** | | | | |
| **4.1** | Macroinvertebrates – Species richness | Sampling substrates and sediments using sieve/net | Decreasing trend in native species | Stable | Increasing trend in native species |
| **4.2** | Vertebrate – Richness and abundance of fish species | Netting, fish traps | Decreasing trend in native species | Stable | Increasing trend in native species |
| **4.3** | Vertebrate species – fish catch % native species | Netting, fish traps. Fishermen survey | Decreasing trend | Stable | Increasing trend |
| **4.4** | Vertebrate – Richness and abundance of Amphibian | Standard Amphibian survey | Decreasing trend in native species | Stable | Increasing trend in native species |
| **4.5** | Vertebrate – Richness and abundance of water birds | Standard water bird survey | Decreasing trend | Stable | Increasing trend |
| **4.6** | Abundance of aquatic invasive fauna | Standard survey for benthic communities and fish catch | Increasing trend | Decreasing trend | No invasive species |
| **4.7** | Habitat suitability for threatened species | Standard habitat assessment | Important habitat parameters have degraded and overall habitat quality has declined | A few habitat parameters required have degraded | Most of the habitat parameters are intact and habitat quality is in best state |
| 5. | | | | | |
| **5.1** | Presence of solid biodegradable andnon-biodegradable waste in water and on shoreline | Field survey | Major portion of the wetland has scattered biodegradable and non-biodegradable waste | Less than 50% area has scattered biodegradable and non-biodegradable litter | Negligible litter in the wetland or wetland free of scattered biodegradable or non-biodegradable litter. |
| **5.2** | Quality and quantity of sewage inflow | Standard IS: 3025- Part I (1987) | >1% of the total volume of wetland water at any given time | 0.5% the total volume of wetland water at any given time | No sewage coming into the wetland |
| **5.3** | Quality and quantity of industrial discharge | Field survey and sample analysis using IS: 3025- Part I (1987) | >1% of the total volume of wetland water at any given. | 0.5% the total volume of wetland water at any given time. | No industrial waste coming into the wetland. |

| | | | | | |
|---|---|---|---|---|---|
| **5.4** | Extent of fishing | Perception of local fishermen. Fishing landing and market surveys. | Substantial decline in catch of native fish species during last 10 years. Decrease in fish catch (CPUE). | Moderate decline in catch of native fish species during last 10 years. | Fishermen reported more or less stable fish catch during last 10 years |
| **5.5** | Extent of biomass extraction | Field surveys. Household interviews. | Substantial biomass extraction | Occasional biomass extraction. | Minimal/Negligible biomass extraction from wetland. |
| **5.6** | Extent of grazing | Field survey. | Grazing animals have access throughout shoreline areas | less than 50% | less than 25% |
| **5.7** | Sand mining, Stone query | Field surveys. Perception of the observer. | Substantial both manual and mechanized tools. Intensity of mining. | Sand and boulder mining on the bank and in water using traditional methods. | No sand or boulder mining on the bank and in water. |
| **5.8** | Washing of clothes, vehicles near the wetland area. | Field observations. | People washing cloths and vehicles using detergents regularly. | People washing cloths and vehicles using detergents occasionally. | No washing of cloths and vehicles in the wetland. |
| **5.9** | Any other activity that may degrade ecosystem | Field surveys. | Substantial human pressure. | Fairly low human pressure. | No human pressure. |
| Sum of score | | | | | |

# 5 Traditional Knowledge Systems for Sustainable Development

## 5.1 Background

Traditional Knowledge Systems (TKS) encompass knowledge holders, their practices, know-how, technologies, cultural beliefs, and institutions that organize production, transfer and use the knowledge (Tengo et al. 2014). Traditional Ecological Knowledge (TEK) which is a sub-set of TKS and practical in nature refers to the knowledge, beliefs and practices pertaining to sustainable livelihoods and use of natural resources inherited by traditional societies through generations (Berkes et al. 2000). TEK helps in understanding the harmonious existence of societies with nature, adaptive strategies in the face of environmental changes and resultant impacts on flow of ecosystem services (Toledo et al. 2003). TEK is well accepted by scientists in the field of agriculture, forestry, pharmacology, water engineering, architecture, ethno-biology, irrigation system, and soil and water conservation (IPCC 2014 and 2018). Accordingly the scientists have been pressing for the acceptance of the epistemological uniqueness of the TEK and emphasizing on the need of placing it at the center of environmental governance to expand the sustainable developmental options and co-production of knowledge (Mistry and Berardi 2016).

In accordance to UN charter on sustainable development, the parties are obliged to identify indicators relevant to traditional knowledge and customary sustainable use of resources (UNEP/CBD/WG8J/8/9, 2013). This is also relevant to the third goal of Convention on Biological Diversity that advocates for documenting traditional knowledge related to use of bio-resources and equitable benefit sharing. These indicators assist in decision making in development planning and monitoring of socio-ecological environment. However, incorporation of traditional knowledge in ecological monitoring process is a challenging task. This is largely due to tremendous variation in resource use practices and lack of clear indicators reflecting the TEK. Moreover, data on the status, trends, persistence or loss of TEK are scanty and it is not clear how the changes in TEK relate to the maintenance or erosion of biodiversity and bio-cultural diversity in the field (Maffi 2007). Although indigenous and ethnic communities inherit vast knowledge on the use and management of biological diversity, so far this knowledge has rarely been mainstreamed into conservation and adaptation planning. Local people observe the change in environmental conditions and its effects on the species which they use in their day-to -day life. Sustainability in developmental process cannot be achieved without involving the local people and considering their ethics and values in the policy and decision making. The decision becomes biased if they are not involved in the process of managing their resources and integrated planning for sustained flow of ecosystem services.

### *5.1.1 Traditional Communities in IHR*

The Indian Himalayan Region (IHR) is not only home to about 25% of the total number (>700) of indigenous groups of the country but also a large number of traditional societies representing diverse culture and traditions. Through generations these communities have inherited rich knowledge and culture pertaining to farming systems, health care systems, architecture, and hunting and gathering. In terms of occupation, depending on their specific location and agro-climatic conditions, these communities can be categorized as nomadic/transhumance pastoralists and subsistence farmers. Agriculture and animal husbandry, which are closely linked to the forestry sector, are the main occupations of the local communities which have sustained their livelihoods through ages. The thriving trans-boundary trade with Tibet was also found in few communities such as Bhotias till 1962 abruptly ended in the aftermath of Sino-Indian conflict.

The traditional communities in the IHR still manage natural resources through local institutions such as *Goba* of Changpas, *Doksa*, *Lorapas* and *Chhurpon* of other indigenous groups of Ladakh in Jammu & Kashmir; *Muqaddam* of Pangwals of Himachal Pradesh; *Lath Panchayats*/*Van Panchayats, Panta, Rakeet* of Uttarakhand; *Dzumsa*, *Dwichi*, *Mutanchilomalshezum* of Sikkim; *Tso* of Monpas, *Nyel* of Nishis, *Kebang* of Adis and *Buliang* of Apatanis of Arunachal Pradesh; *Keloa Samkahekibe* of Zemes of Assam; *Hanga* of Tangkhuls of Manipur; *Syiemshi*p of Khasis, *Doloiship* of Jaintias and *Ri Raid* and *Ri Kynti* types of *Jhum* in Meghalaya; *La Upa* of Mizos*;* *Morung* of Nagas of Nagaland; Sacred Groves distributed across the region etc., to name a few among numerous others (Gadgil and Vartak 1974; Ramakrishnan 1992; Ramakrishnan et al. 1998; Singh 1997; WWF-India 2004; Pathak 2009; Semwal et al. 2012; Garkoti et al. 2018). Such local institutions vary from community to community in composition, powers and privileges yet there are certain features in common. These are local governance institutions reflect upon the aspirations of all members of concerned society and are constituted by its elderly, knowledgeable and respected persons.

Fortunately, of late, a few of these non-formal entities of the IHR, particularly in the north-eastern states are being appreciated by the formal regime albeit in a limited way for the role they had and have been playing in sustainable development at local level. However, literature describing actual participatory practices of ecosystem management from the IHR is still scanty, limited in its influence and restricted only to a handful of examples such as Nagaland Empowerment of People through Energy Developmen (NEPED) in Nagaland, Community Conserved Areas in western Arunachal Pradesh, Holy Lake Welfare Society at Khechiopalari in Sikkim, Van Panchayats in Uttarakhand, Daikong- Bolong now known as Asha Van in Tripura, JFM in few selected forest divisions across different state in IHR (Planning Commission Task Force Report 2010) and traditional Amchi system of healthcare in Ladakh .

The IHR is facing several challenges such as loss of biological, linguistic, cultural and institutional diversity resulting in decline of TEK due to changes in various spheres such as socio-economy, policies and institutions, land use and land cover, acculturation and more importantly in climate. In addition, out migration of young people in search of better livelihoods, unstable population and occupational transformation are some of the immediate threats to the TKS in the region. However, there are no estimates of the rates at which these diversities erode. Once such knowledge is eroded, it is very difficult to restore unless such knowledge is documented.

This chapter outlines the broad approach of evaluating health status of TKS/TEK adopted during the ongoing process of knowledge documentation among various ethnic/traditional groups across the IHR. To begin with, it identifies broad parameters of TEK and indicators (which can be refined further) for qualitative and quantitative assessment using common methodology across various eco-cultural zones (traditional territories) /study areas in the IHR.

## 5.2 Methodology and approach to assess the status of TEK

### *5.2.1 General*

The Task Force -5 of the NMSHE is a network programme on documentation of Traditional Knowledge Systems (TKS) among traditional societies and indigenous groups of the Indian Himalayan region (IHR) so as to formulate appropriate strategies for integrating such knowledge for sustainable development in the region. However, under the influence of modernity the knowledge base is eroding at an alarming rate in the region in present times. Following major elements of TKS elements (IIRR 1996) are being documented in integrated manner by the Task Force as per their local importance in different eco-cultural zones/ study area identified across the IHR states:

i. **Information or Pointers** on indicator plant or animal species to determine habitat quality, predicting weather, maintaining ecosystem services.
ii. **Practice & Technologies** pertaining to farming, livestock husbandry, health care, water mills, fiber extraction from plants, architecture, handicraft making, seed and food storage.
iii. T**ools and materials** used in house construction, making agricultural implements, wood processing and carving, wool processing and knitting, and cooking, handicrafts, and water mills.
iv. **Use and processing of bio-resources** including medicinal herbs for traditional health care, subsidiary food, and other non-timber forest products.
v. **Experimentation and Innovations, i.e.,** new species introduction by farmers, farming practices, new medicine by traditional healers, and bio-prospecting.
vi. **Cultural Beliefs and Taboos** related to nature worship, preservation of sacred groves, sites of religious significance, rituals and ceremonies.
vii. **Social Capital** i.e., traditional institutions, traditional healers/blacksmiths/carpenters/trainers.
viii. **Inheritance of traditional knowledge** especially transfers of knowledge to younger generations, and learning through observations

ix. **Communication** through folk stories/songs/proverbs/ messages/taboos/dances/folk media, and traditional institutions

The qualitative and quantitative data on various aspects of TEK were collected following the standard methods (Common Methodology Framework developed by the Task Force in 2015). Based on an initial exhaustive list of traditional practices, eight (08) TEK themes and twenty-five (25) indicators were selected around them for the quantitative assessment of the current status of TEK among as many as 26 of the identified communities. Further, the TEK indicators across the selected themes/parameters were given tentative threshold values to determine their status as 'Intact', 'Eroding slowly', 'Eroding fast' and 'Eroded' among the studied communities (Table 5.1).

The broad TEK themes and corresponding indicators selected are as follows:

**i.** ***Traditional Healthcare System:*** Maternal and child care; Sanitation and cleanliness of drinking water; Status of knowledge on traditional healthcare;

**ii.** ***Food Habits and Food Security****:* Livelihoods; food security, sustainable use of natural resources;

**iii.** ***Farming and Agriculture****:* Traditional cropping system; livestock management practices; traditional occupation; status of socio-economic transformation; management of weeds, pests and crop raiding by wild animals; livestock management practices; knowledge of flora and dependency on forests;

**iv.** ***Natural Resource Management****:* Knowledge of natural resource availability and sustainable use; dependency on forest and particular species of plants; market economy; over exploitation of natural resources;

**v.** ***Culture****:* Traditional beliefs and customs; history and experience;

**vi.** ***Traditional Architecture****:* Local climate adaptation strategy and vernacular architecture; pressure on forest ecosystem;

**vii.** ***Knowledge Transfer****:* Transfer of TEK and loss;

**viii.** ***Demographic Vulnerability****:* Environmental degradation; declining population and gender inequality.

Though conscious efforts were made to maintain the uniformity in TEK themes and indicators across the studied communities, the required tentative threshold values on all the indicators across selected communities and themes uniformly could not be achieved due to variation in cultural traits and prevailing biophysical conditions in the study areas/eco-cultural zones inhabited by them (Table 5.1). However, these were found useful in observing and estimating the TEK status under heterogeneous cultural attributes of the selected communities and biophysical conditions in the specific study areas.

### *5.2.2 Literature Survey at Pan-Himalayan Scale*

An extensive literature survey was conducted for the entire IHR across 100 relevant national and international journals/magazines for at least last 15 years (mainly between years 2000 and 2015) to assess the knowledge status in the IHR. Nearly 3000 volumes and 9000 issues of the aforementioned journals were browsed including the Indian Journal of Traditional Knowledge to survey the literature on various TKS themes of the IHR. Further, based on the previous findings a total 40 most important journals were prioritized for surveying the published papers between 2016 and 2018 in order to update the status and understand the knowledge documentation trend on various TKS themes in the IHR.

## 5.3 Status of knowledge and trends

### *5.3.1 General*

The literature surveyed reveals that about 876 research papers/articles published on different TEK themes/ dimensions of the IHR in the aforesaid number of journals and magazines between 2000 and 2015. Across the IHR, Uttarakhand, Himachal Pradesh, Arunachal Pradesh and J&K are the most explored (contributing for 63% of the total publications) states and Mizoram, West Bengal Hills, Tripura and Nagaland are the least explored states in the region in terms of number of publications on various categories/dimensions of TEK (Figure 5.1a).

Of the total publications, majority (about 70%) deal with TEK concerning ethno-medicine, ethno-botany, farming, and natural resource conservation and use (Figure 5.1b). However, published information on important themes like traditional knowledge on climate change adaptation and mitigation, disaster management, folk forecasting of weather, management of human-wildlife conflicts, livelihoods and gender dimensions still very less documented (Figure 1b).

A total of 179 additional peer reviewed research papers on various TEK themes appeared in about 40 surveyed journals/books between 2016 and 2018. Though again nearly 62% of the recent publications are from the four IHR states viz., Uttarakhand, Himachal Pradesh, J&K and Arunachal Pradesh; publications from states like Sikkim, Manipur and Nagaland have slightly picked up during last three years (Figure 5.1c). Of late, the hitherto less explored TKS themes related to climate change adaptation, disaster management and weather forecasting alongside livelihoods and wild edibles have also drawn some attention of the researchers in the region (Figure 5.1d). In all a total of 1055 research papers/articles have been published by various workers between 2000 and 2018 from all IHR states on different TEK themes in the surveyed research journals and books (Figure 5.1e,f)

Despite huge amount of published information, it remains scattered across multiple sources requiring a thorough analysis and synthesis of the documented knowledge for its possible up-scaling, policy uptake and identifying knowledge gaps and deficiencies in documentation approach.

**Table 5.1. Tentative threshold of indicators and measures of key areas of TEKs among studied communities**

| TEK Theme | Indicator | Measures | Tentative Thresholds of TEK | | | | No of studied communities |
|---|---|---|---|---|---|---|---|
| | | | Eroded | Eroding Fast | Eroding slowly | Intact | |
| **Traditional Healthcare System** | Maternity and Child care | Presence of traditional birth attendants in community | Absent | Very few | Few | Sufficient | 5 |
| | Sanitation and cleanliness of drinking water | Sanctity and cleanliness of water courses | Complete loss | >75% loss | 25 - 75% loss | <25% loss | 19 |
| | Traditional Healthcare knowledge | Percent of population having such knowledge | 0-15% | 15-30% | 30-45% | >45% | 22 |
| **Food Habits and Food Security** | Livelihood adaptation and weather stress adaptation strategy | % population having knowledge on coping strategies | 0-15% | 15-30% | 30-45% | >45% | 18 |
| | Traditional food system | % people having knowledge of subsidiary food and food storage system | 0-20% | 20-40% | 40-60% | >60% | 22 |
| **Farming Practice** | Traditional Farming Practices | % people still practicing Apiculture, sericulture, and other practices | 0-5% | 5-10% | 10-20% | >20% | 25 |
| | Traditional crops and organic manure | % Households using traditional seeds and organic manure | <20% | 20-40% | 40-60% | >60% | 19 |
| | Livestock management practices | Percentage of households having livestock | <20% | 20-40% | 40-60% | >60% | 15 |
| | | % of human population in community with knowledge on traditional livestock management | <20% | 20-40% | 40-60% | >60% | 17 |
| | Traditional occupational status | % of population involved in traditional occupation | <20% | 20-40% | 40-60% | >60% | 18 |
| | Socio-economic transformation | Percentage of population in service sector/other fields | >60% | 40-60% | 20-40% | <20% | 17 |
| | Knowledge of weeds and pests | % of farmers population having knowledge of weeds and pest and their management | <20% | 20-40% | 40-60% | >60% | 19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Crop selection | Number of Knowledge holder; weather forecast and soil fertility | Absent | 1or 2 | few | Most of the people | 16 |
| | Agricultural implements | Number of expert people in making agricultural implements using locally available resources | Absent | 1or 2 | few | Most of the people | 18 |
| **Natural Resource Managemen t** | Knowledge on sustainable use of forest resources | Mean % of population having knowledge on all kinds of NTFPs | <20% | 20-40% | 40-60% | >60% | 20 |
| | Dependency on forest resources | Presence of indicator species | Absenc e | Rare | Common | Abundant | 14 |
| | Over exploitation of forest resources | Density of economically important plant in nearby forest | Absenc e | Rare | Common | Abundant | 6 |
| **Culture** | Traditional beliefs and customs | %of population using traditional costumes and having their beliefs in customs | <40% | 40-60% | 60-80% | >80% | 24 |
| | History and experience | Folklores | Absent | Very few in number | Few in number | High in number | 19 |
| **Traditional Architecture** | Local climate adaptation strategy and Vernacular architecture | No. of traditional houses in village | <40% | 40-60% | 60-80% | >80% | 25 |
| | Load on forest ecosystem | Density of preferred plant species required by the community in nearby forest | Absent | Very less | Less | Abundant and managed | 12 |
| **Knowledge Transfer** | Transfer of TEK | Knowledge Richness Index | >0.75 | 0.51-0.75 | 0.26-0.50 | <0.25 | 10 |
| | Loss of TEK | Out migration % | >75% | 50-75% | 25-50% | <25% | 19 |
| **Demographic Vulnerability** | Environmental degradation | % of farmers using chemical pesticides | >30% | 20-30% | 10-20% | <10% | 14 |
| | Population trend and gender | Population Structure (Population Pyramids), gender-occupation relationship | - | - | - | - | 0 |

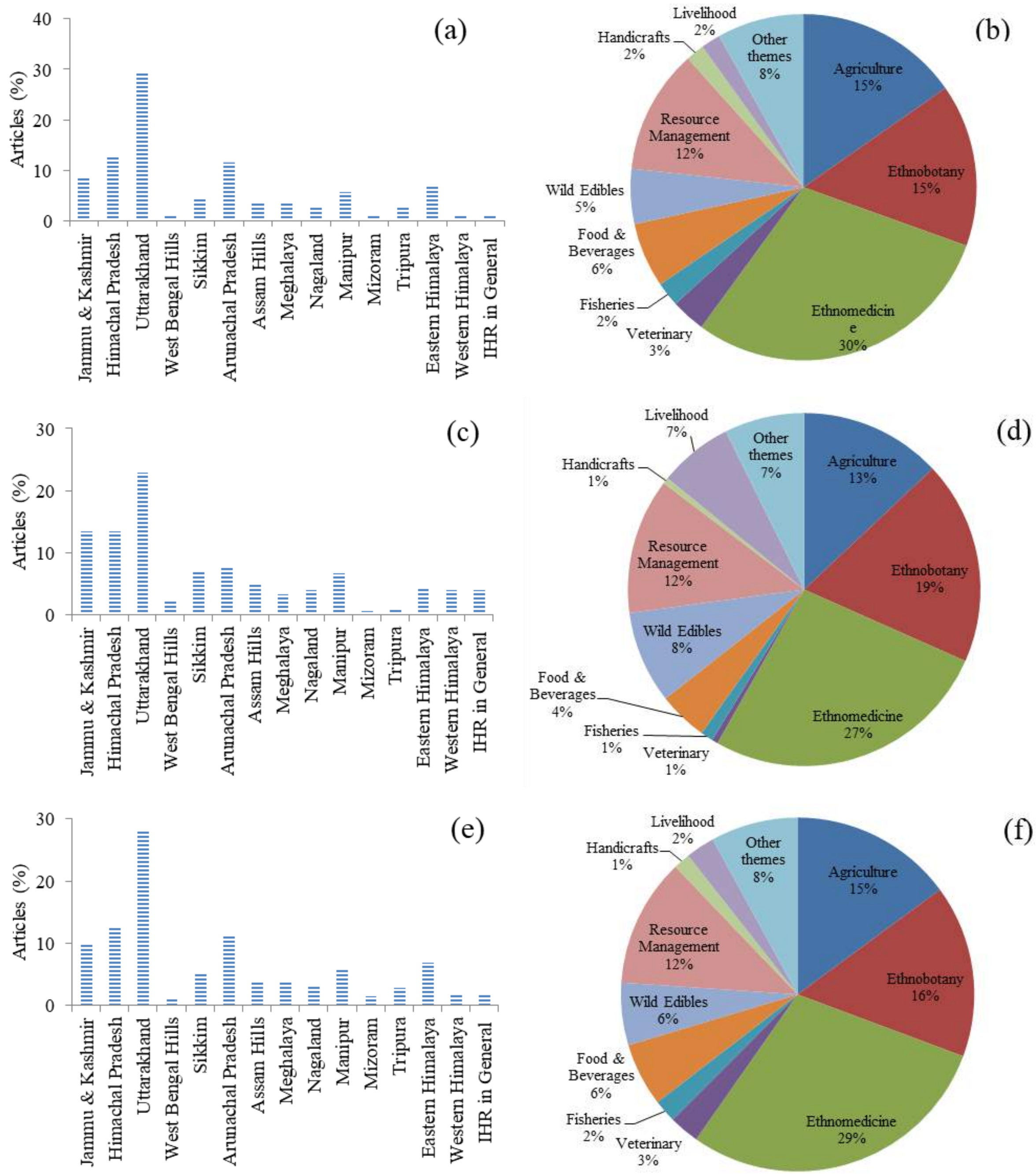


**Figure 5.1: Percentage of the total articles published in research journals on TEK from different IHR states and themes, (a) & (b) is from 2000-15, (c) & (d) from 2016-18 and (e) & (f) from 2000-18.**

**Note:** **Other themes include, Ethno-zoology, Grain Storage, Weather Forecasting/ Prediction, Climate Change Adaptation, Disaster Management and Miscellaneous.**

### *5.3.2 Trends of TEK among the selected communities*

Rapid assessment based qualitative indicators for various TEK themes of selected communities in the identified eco-cultural zones across IHR states such as Pohols/Pahills of Kashmir valley; Spitians/Bodhs, Kinnauras, Gaddis and some traditional communities in Chamba, Kangra, Kinnaur, Spiti and Una districts of Himachal Pradesh; Jaunsaris, Jaads and Van Gujjars in Uttarakhand; Nepalis, Bhutias and Limbus in Sikkim; Garos and Jaintias in Meghalaya; Hmars in Manipur; Khelmas and Zemes in Hill areas of Assam; and Aos, Lothas, Kukis and Zeliangs of Nagaland were developed for understanding the trend of erosion of their TEK. Among most of these communities, the TEK across the themes is eroding at different pace in different eco-cultural zones under the influence of modernization.

The quantitative assessment of TEK themes among the 26 studied communities shows that none of these are immune from the standpoint of erosion in their TEK which is eroding at varied pace among different communities (Table 5.2). However, while communities viz., Lepchas and Sherpas of Sikkim, Tangkhuls of Manipur, Karbis of Assam hills, Pangwals of Himachal Pradesh, and Gujjars and Bakerwals of Jammu and Kashmir have still been able in retaining a sizable elements of their TEK, however, among Adis of Arunachal Pradesh, Reangs and Tripuri of Tripura, Mizos of Mizoram and Gujjar of Pangi valley of Himachal Pradesh none of the studied elements were observed as intact (Table 5.2). However, in some instances local innovations, adoption of new technologies and materials from outside and increasing market demand have been found to be assisting in retaining/ reinvigoration of certain elements of TEK among a very few communities in specific locations/study areas. . For example, adoption of modern tools for traditional handloom making, growing demand for traditional organic food, fruits and medicines are not only helping people in retaining traditional knowledge albeit in a very few eco-cultural zones.

### *5.3.3 Status of TEK among the Selected Communities*

So far as status of selected TEK themes/parameters is concerned, it also showed varied patterns of erosion across themes and communities (Figure 5.2). Though sizable number of the communities has lost their traditional healthcare knowledge, the sanitation and cleanliness practices are still intact among majority of the studied communities. The traditional food and food habits have been changing drastically among sizable number of the communities. Similarly traditional farming practices except use of organic manure and traditional crops up to certain extent, indicators showed different levels of erosion in various farming practices among the communities. Indicator related to dependence on natural resources has shown substantial decline on natural resources in most of the communities while increase in over-exploitation of resources due to erosion in their sustainable harvesting practices. Indicator of culture showed sharp decline in its value among most of the communities. Sizable numbers of the communities are losing their vernacular architectural knowledge while increasing out migration of young community members has been observed impacting the process of knowledge transfer (Figure 5.2). Acculturation, urbanization and modernization due to increasing literacy, out migration, loss of local language/dialect and top-down policies driven changes on traditional institutions and sectors are some of the key factors responsible for erosion of TEK among the studied communities.

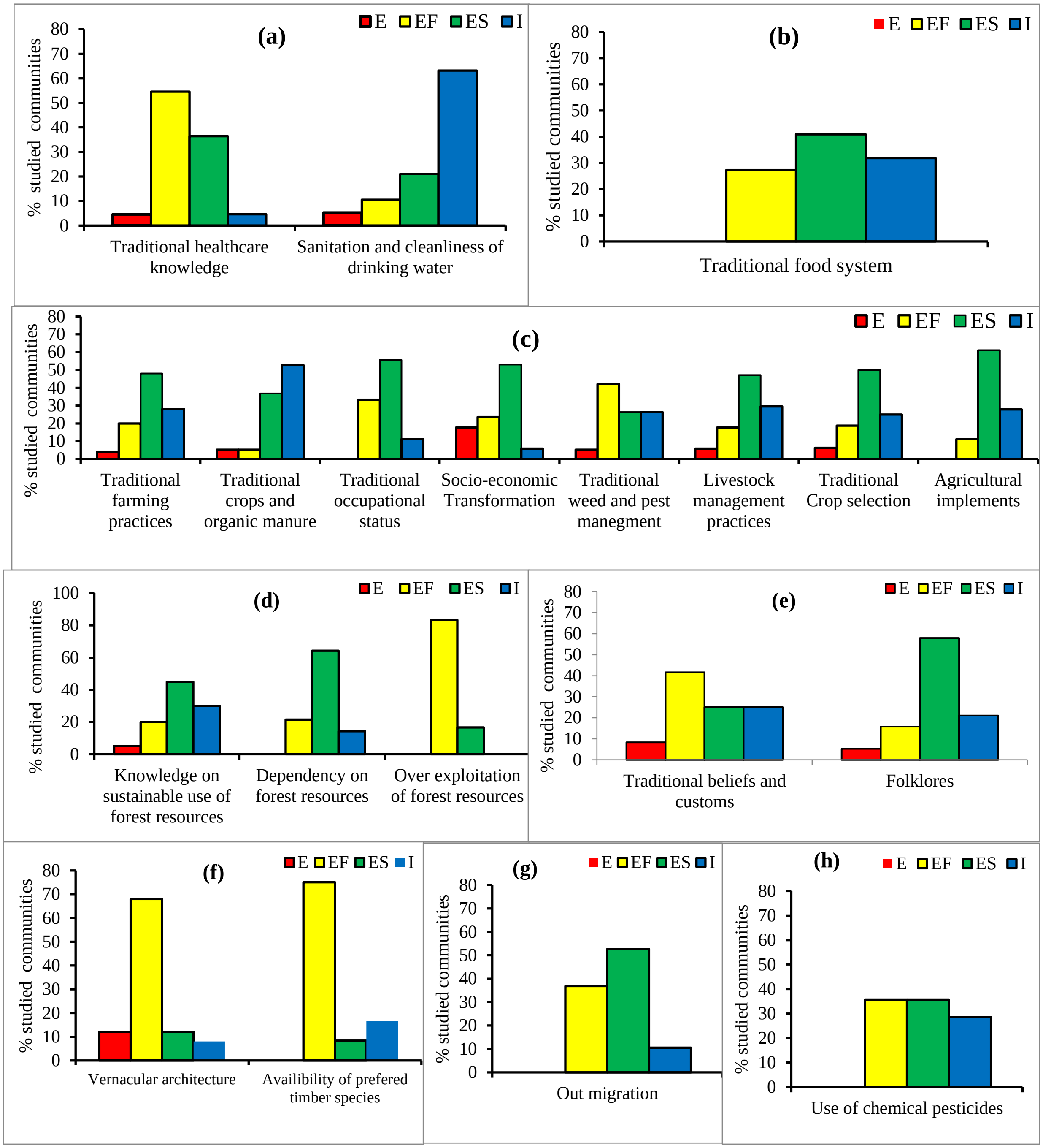


**Figure 5.2: Health status (E-Eroded, EF-Eroding fast, ES-Eroding slowly and I- Intact) of different TEK themes among the studied communities across the IHR: (a) Healthcare system (b) Food and food habits (c) Farming system (d) Natural resource management (e) Culture (f) Traditional architecture (g) Knowledge transfer and (h) Demographic vulnerability**

**Table 5.2: Cumulative health status of selected TEK themes/parameters among the studied communities in Indian Himalayan Region**

| Community | Study Area | Status of TEK across selected themes/parameters | | | | | | | | Total indicators estimated across selected TEK themes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Eroded | | Eroding fast | | Eroding slowly | | Intact | | |
| | | Number of Indicators observed | % of total indicators | Number of Indicators observed | % of total indicators | Number of Indicators observed | % of total indicators | Number of Indicators observed | % of total indicators | |
| Adi | Upper Siang, Arunachal Pradesh | 0 | 0 | 3 | 15.00 | 17 | 85.00 | 0 | 0 | 20 |
| Apatani | Lower Subansiri, Arunachal Pradesh | 0 | 0 | 2 | 10.00 | 13 | 65.00 | 5 | 25 | 20 |
| Barpatiya | Pithoragarh, Uttarakhand | 1 | 5.26 | 6 | 31.58 | 7 | 36.84 | 5 | 26.32 | 19 |
| Biate | Dima Hasao, Assam | 2 | 10.53 | 11 | 57.89 | 2 | 10.53 | 4 | 21.05 | 19 |
| Gujjar and traditional communities | Tissa Valley, Himachal Pradesh | 0 | 0 | 10 | 58.82 | 7 | 41.18 | 0 | 0 | 17 |
| Gujjars/Bakerwals | Marwah and Bungus valley, Jammu & Kashmir | 0 | 0 | 3 | 12.25 | 10 | 41.66 | 11 | 45.83 | 24 |
| Haenz | Dal and Anchar lakes, Jammu & Kashmir | 7 | 33.33 | 2 | 9.52 | 10 | 47.61 | 2 | 9.52 | 21 |
| Karbi | Dima Hasao, Assam | 1 | 5.26 | 8 | 42.11 | 4 | 21.05 | 6 | 31.58 | 19 |
| Khasi | East Khasi hills, Meghalaya | 1 | 8.33 | 4 | 33.33 | 2 | 16.66 | 5 | 41.66 | 12 |
| Ladakhi communities | Leh valley, Jammu & Kashmir | 0 | 0 | 5 | 29.41 | 10 | 58.82 | 2 | 11.76 | 17 |
| Lagaal | Lug valley, Himachal Pradesh | 1 | 5 | 6 | 30 | 11 | 55.00 | 2 | 10 | 20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lepcha | North Sikkim, Sikkim | 1 | 4.35 | 2 | 8.70 | 5 | 21.75 | 15 | 65.1 | 23 |
| Mandyaal | Barot valley, Himachal Pradesh | 1 | 4.76 | 7 | 33.33 | 11 | 52.38 | 2 | 9.52 | 21 |
| Mao | Senapati district, Manipur | 0 | 0 | 4 | 80.00 | 0 | 0 | 1 | 20 | 5 |
| Meitei | Jiribam, Manipur | 0 | 0 | 2 | 66.60 | 0 | 0 | 1 | 33.3 | 3 |
| Mizo | Aizwal district, Mizoram | 0 | 0 | 1 | 25.00 | 3 | 75.00 | 0 | 0 | 4 |
| Monpa | West Kameng, Arunachal Pradesh | 0 | 0 | 2 | 10.00 | 13 | 65.00 | 5 | 25 | 20 |
| Pangwal and Bhot | Pangi, Himachal Pradesh | 0 | 0 | 0 | 0 | 8 | 53.33 % | 7 | 46.66 | 15 |
| Reang | Chawmanu and Vangmun, Tripura | 0 | 0 | 2 | 66.67 | 1 | 33.33 | 0 | 0 | 3 |
| Sherdukpen | West Kameng, Arunachal Pradesh | 1 | 5.00 | 13 | 65.00 | 5 | 25.00 | 1 | 5 | 20 |
| Sherpa | South Sikkim, Sikkim | 1 | 4.35 | 2 | 8.7.0 | 8 | 34.80 | 12 | 52.2 | 23 |
| Swangla | Pattan valley, Himachal Pradesh | 1 | 4.76 | 4 | 19.04 | 9 | 42.85 | 7 | 33.33 | 21 |
| Tangkhul | Ukhrul, Manipur | 0 | 0 | 2 | 50.00 | 0 | 0 | 2 | 50 | 4 |
| Traditional Hill communities of Uttarakhand | Saryu valley and Garur Ganga valley, Uttarakhand | 0 | 0 | 12 | 57.00 | 8 | 38.09 | 1 | 4.76 | 21 |
| Tripuri | Chawmanu and Vangmun, Tripura | 0 | 0 | 2 | 66.67 | 1 | 33.33 | 0 | 0 | 3 |
| Van Raji | Pithoragarh, Uttarakhand | 2 | 14.29 | 7 | 50.00 | 3 | 21.43 | 2 | 14.29 | 14 |

## 5.4 Challenges

In the absence of baseline information on TEK among identified communities, it is rather difficult to compare the trends related to all the parameters. Moreover, quite a few communities in the IHR are resilient and rapidly acquiring new knowledge and tools related to use of natural resources. Use of reliable indicators against major parameters and standardization of thresholds that reflect various categories such as intact, eroding, rapidly eroding, reinvigorating TEK are some of the challenges of this assessment.

Establishing relationships with the status of TEK among various communities and sustainability of their natural environment would require in-depth analysis of documented knowledge and robust methodological design. Traditional knowledge concerning Climate Change is often weather related knowledge rather than fully evolved knowledge and practices that can be passed down to generation to generation to respond to the multiple challenges that the climate change is posing in present times (Berkes 2012). Nevertheless, there are many local climate adaptive practices which emerged in response to changes/variability in weather for centuries, required to be carefully identified and documented.

## 5.5 Way Forward

Efforts to document and assess TEK have grown exponentially in recent times considering its increasing global recognition for sustainable management of ecosystems. Based on ongoing work, a preliminary attempt has been made to develop some standardized indicators of TEK in qualitative and wherever possible quantitative terms for understanding its status among some of the identified indigenous groups/traditional societies inhabiting different eco-cultural zones in the IHR. The indicators helped providing broad information on aspects viz., (i) status of knowledge in terms of its intactness and different pace of erosion, and (ii) which identified TEK themes are most vulnerable and the causal factors. However, considering the complexity of issues involved and lack of baseline, no qualitative or quantitative indicator can provide precise measure of TEK in different cultural milieus and environmental situation across the IHR.

In order to understand the climate change impacts on diverse traditional practices linked to farming, natural resource use and management and healthcare system, efforts are required towards preparation of traditional ecological calendars/health calendars for identified communities/eco-cultural zones in the IHR depicting changes/shifts/adjustments observed. The calendars so prepared may help developing models to record the shift in activities/ traditional indicators concerning farming systems, natural resource use including water while decoupling such shifts from other changes taking place in socio-economic, policy and institutional and technological spheres. So far knowledge related to a range of wild plant species used and managed for food, fodder, fuel wood, fiber, timber and most importantly for medicine by a number of local communities has been documented. Similarly, information has been recorded on different aspects of a variety of traditional farming systems, local innovative farming practices and natural resource based livelihood earning traditions of the identified communities. The programme has been able to record a number of traditional crops/cultivars and natural resources based food items/cuisines from diverse eco-cultural zones in the IHR alongside their nutraceutical properties as perceived by traditional communities. The information being collected on the aforementioned aspects may add new species/traditional formulations in the national bio-prospecting database and generate opportunities for researchers to find scientific evidences behind such knowledge and practices. Besides the abovementioned aspects/themes, presently the ambit of knowledge documentation process ranges local governance institutions, house architecture, local weather prediction, human-wildlife conflict mitigation and so on of various communities in different eco-cultural zones/study areas.

The parameters and indicators selected and tested in this assessment need to be refined, standardized, replicated and up-scaled further across studied communities in the IHR. Efforts would be made to develop similar broad scenarios for other identified groups in the region reflecting the status of TEK in both qualitative and quantitative terms. However, in future the developed indicators may be used or condoned purposefully depending on the context in hand and lessons learned would be utilized for developing future indicators. In addition, attempts can be made to develop indicators that take into account both documented knowledge in various published sources while combining the results of ongoing programme. Long term monitoring of selected parameters through the network programme would go a long way in understanding the status of TEK in the region in terms of how erosion of knowledge is affecting the sustainability of identified themes and how factors of change including policies are helping in preservation and protection of TEK on one hand and minimizing erosion or its restoration/reinvigoration on the other.

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*Annexure I*

## Traditional and indigenous communities being studied in the IHR

| S. No. | Coordinating Institute/ Network Partners | State | Study area/ Eco-cultural zones/ District | Community | TKS themes being documented with focus on Climate Change and Gender perspectives |
|---|---|---|---|---|---|
| 1 | Jawaharlal Nehru University, New Delhi | J&K | Leh | Boto, Mon, Beda, Gara and Brokpa | Agro-forestry, Traditional institutions, Food storage, Healthcare systems, Traditional calendar |
| | | Himachal Pradesh | Kinnaur, Shimla, Sirmaur, Una and Kangra | Kanaura, Rai community, Gaddi, and Traditional farming community | Traditional institutions, Farming practices, Natural resource use and management, Handicraft, Traditional calendar |
| | | Uttarakhand | Dehradun | Gujjar | Livestock management and Pastoralism , Traditional calendar |
| | | Assam | Dima Hasao and KarbiAnglong | Karbi, Biate, Zeme and Khelma | Shifting cultivation, Ethno-mycology, Seed storage, ethno-pedology, Traditional institutions, Traditional calendar |
| 2 | Kashmir University, Srinagar | J&K | Kashmir valley & its side valleys such as Gurez, Tulail (North Kashmir), Warwan, Marveh (South-East Kashmir), Keran and Karnah , Kulgam, Budgam and Ganderbal | Gujjar, Bakerwals, Pahills, Hanz, Dardi-shenai, Wadwani, Arim, Gruss and Traditional Artisans | Pastoralism, Traditional handicrafts, Agriculture and fisheries, Natural resource use and management, Wood and wool based handicraft, Traditional calendar |
| 3 | CAZRI, Regional Research Station, Leh | J&K | Central, Changthang and Sham belts of Cold Desert/Leh-Ladakh | Indigenous communities of the study area | Agro-pastoralism, Water management, Food & seed storage, Architecture, Healthcare systems, Technologies, Festivals |
| 4 | IHBT, Palampur | Himachal Pradesh | Chamba | Gaddi, Gujjar and Pangwal | Pastoralism, Agriculture, Sacred grooves, Healthcare systems |
| 5 | GBPNIHESD, Almora | Himachal Pradesh | Lahaul&Spiti, Kullu and Mandi, | Gari, Todpa, Swangla, Tinnanba, Pitishag, Malani, Jecha, Siraji, Lagad, Mandayal and Gaddi | Land and soil management, Water resource management, Bio-resource management and conservation |

| | | | | | |
|---|---|---|---|---|---|
| | | Uttarakhand | Bageshwar | Non-Tribal indigenous communities | Land and soil management, Agrobiodiversity conservation, healthcare systems |
| | | Sikkim | South district and East district, West district | Rai (Nepali), Bhutia, Lepcha and Limbu | Food processing, Land and soil management |
| | | Arunachal Pradesh | West Kameng, Upper Siang and Lower Subansiri | Monpa, Adi and Apatani | Traditional agriculture systems, Traditional institutions, Ethnobotany, Bio-resources management |
| | | Nagaland | Mokokchung,Wokha and Peren district | Ao, Lotha, Kuki and Zeliang | Farming, Natural resource management |
| 6 | Doon University, Dehradun | Uttarakhand | Uttarkashi and Dehradun | Jaad and Jaunsari | Natural resource management, Food processing, Traditional handlooms, Traditional technologies |
| 7 | Wildlife Institute of India, Dehradun | Uttarakhand | Pithoragarh | Barpatiyas and Van Rajis | Food processing, Traditional farming and agriculture, Natural resource management and Healthcare systems |
| 8 | North-Eastern Hill University, Shillong | Meghalaya | East Khasi Hills, West Khasi Hills, RiBhoi, Jaintia Hills, West Garo Hills, East Garo Hills and South Garo Hills | Khasi, Garo and Jaintia/Pnars | Pest management, Agroforestry systems, Natural resource management |
| | | Mizoram | Aizawl and Champhai | Mizo | Ethno-botanical knowledge, Agroforestry systems, Food and grain storage systems |
| | | Tripura | Dhalai | Tripuri, Reang, Chakma and Jamatia | Faming and natural resource management practices |
| | | Manipur | Imphal East and Senapati | Meitei,Thadou, Kabui, Tangkhul, Mao and Hmar | Ethno-botanical knowledge, Agroforestry systems, Storage systems, Food processing |

## *Annexure-2*

**Status of Traditional Ecological Knowledge among Barpatiya and Van Raji Communities of Pithoragarh District, Uttarakhand**

| S. No | Key areas of TEK | Indicator | Measure | Tentative Thresholds of TEK | | | | Current Status among Barpatiyas | Current Status among Van Rajis |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Eroded | Eroding Fast | Eroding slowly | Intact | | |
| 1 | Traditional Healthcare System | Maternity and Child care | Presence of traditional birth attendants in community | Absence of any birth attendants | Present in the recent past | Very few present in the community | Quite a few in the community | Not Analyzed | Not Analyzed |
| 2 | | Sanitation and cleanliness of drinking water | Sanctity and cleanliness of water courses | 100% loss of such system | >75% loss | 25 - 75% | <25% loss | Intact | Eroding fast |
| 3 | | Traditional Healthcare knowledge | Percent of population having such knowledge | 0-15% | 15-30% | 30-45% | >45% | Eroding slow | Eroding fast |
| 4 | Food Habits and Food Security | Livelihood adaptation and weather stress adaptation strategy | % population having knowledge on coping strategies | 0-15% | 15-30% | 30-45% | >45% | Intact | Eroding fast |
| 5 | | Food Security | % people having knowledge of subsidiary food and food storage system | 0-20% | 20-40% | 40-60% | >60% | Eroding fast | Eroding slow |
| 6 | | Traditional Farming Practices | % people still practicing Apiculture, sericulture, and other practices | 0-5% | 5-10% | 10-20% | >20% | Eroding fast | Eroding slow |

| S. No | Key areas of TEK | Indicator | Measure | Tentative Thresholds of TEK | | | | Current Status among Barpatiyas | Current Status among Van Rajis |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Eroded | Eroding Fast | Eroding slowly | Intact | | |
| 7 | Farming practices | Traditional cropping system | % Households using traditional seeds and organic manure | <20% | 20-40% | 40-60% | >60% | Intact | Not Analyzed |
| 8 | | Livestock management practices | Percentage of households having livestock | <20% | 20-40% | 40-60% | >60% | Eroding fast | Not Analyzed |
| 9 | | Traditional occupational status | % of population involved in traditional occupation | <20% | 20-40% | 40-60% | >60% | Eroding slow | Eroding fast |
| 10 | | Socio-economic Transformation | Percentage of population in service sector/other fields | >60% | 40-60% | 20-40% | <20% | Eroding slow | Intact |
| 11 | | Knowledge of weeds and pests | % of farmers population having knowledge of weeds and pest and their management | <20% | 20-40% | 40-60% | >60% | Not Analyzed | Eroding fast |
| 12 | | Livestock management practices | % of human population in communitywith knowledge on traditional livestock management | <20% | 20-40% | 40-60% | >60% | Eroding slow | Intact |
| 13 | | Crop selection | Weather Forecast and traditional soil fertility testing methods | Absent | Only one/two knowledge | Present in few elders | Present in most of the elders | Eroded | Not Analyzed |

| S. No | Key areas of TEK | Indicator | Measure | Tentative Thresholds of TEK | | | | Current Status among Barpatiyas | Current Status among Van Rajis |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Eroded | Eroding Fast | Eroding slowly | Intact | | |
| | | | | | holder found | | | | |
| 14 | | Knowledge of flora and dependency on forest | Knowledge on the use of different woods for various tools | Absent | Only one/two knowledge holder found | Present in few elders | Present in most of the elders | Eroding slow | Not Analyzed |
| 15 | Natural Resource Management | Knowledge of traditional natural resource availability and sustainable use | Mean % of population having knowledge on all kinds of NTFPs | <20% | 20-40% | 40-60% | >60% | Intact | Eroded |
| 16 | | Dependency on forest and particular species of plants | Forest type and cover around village | Absence of indicator species | Very few presence of indicator species | Less abundance of indicator species | Rich of indicator species | Not Analyzed | Not Analyzed |
| 17 | | Market economy, over exploitation of natural resources | Density of indicator plant species sold/required by the community/group in nearby forest | Absence of indicator species | Very few presence of indicator species | Less abundance of indicator species | Rich of indicator species | Not Analyzed | Not Analyzed |
| 18 | Culture | Traditional believes and customs | Mean %of population using traditional costumes/dresses,and having their beliefsin customs | <40% | 40-60% | 60-80% | >80% | Eroding slow | Eroded |

| S. No | Key areas of TEK | Indicator | Measure | Tentative Thresholds of TEK | | | | Current Status among Barpatiyas | Current Status among Van Rajis |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Eroded | Eroding Fast | Eroding slowly | Intact | | |
| 19 | | History and experience | Folklores | Absent | Very few community | Present in very few villages | Present | Eroding fast | Eroding slow |
| 20 | Traditional Architecture | Local climate adaptation strategy and Vernacular architecture | No. of traditional houses in village | <40% | 40-60% | 60-80% | >80% | Eroding fast | Not Applicable |
| 21 | | Load on forest ecosystem | Density of prime plant species required by the community/group in nearby forest | Absent | Very low density | Less available | Abundant and managed | Not Analyzed | Not Analyzed |
| 22 | Knowledge Transfer | Transfer of TEK | Knowledge Richness Index (KRI)(Araújo et al. 2012) | >0.75 | 0.51-0.75 | 0.26-0.50 | <0.25 | Eroding slow | Eroding fast |
| 23 | | Loss of TEK | Out migration % | >75% | 50-75% | 25-50% | <25% | Eroding slow | Eroding fast |
| 24 | Demographic Vulnerability | Environmental degradation | % of farmers using chemical pesticides | >30% | 20-30% | 10-20% | <10% | Not Analyzed | Not Analyzed |
| 25 | | Population trend and gender | Population Structure (Population Pyramids), gender-occupation relationship | - | - | - | - | Intact | Not Analyzed |

# 6 Himalayan Agriculture

## 6.1 Background

The Indian Himalayan Region (IHR), an ecologically fragile landscape spread over 53.7 million ha, is inhabited by over 51 million people who practice hill agriculture for sustenance on 13.6 % of the total IHR area. Major components of Himalayan agriculture include crops, livestock, horticulture, fisheries and agroforestry and it shows great diversity within different geographic regions of this mountain system. Himalayan agriculture is also susceptible to various natural and anthropogenic factors, and it faces constraints such as small and fragmented holdings, undulating terrains, limited scope for irrigation and farm mechanization, poor soil quality, limited resource availability, inadequate processing, storage, and marketing facilities for produce, besides man-animal conflicts causing crop damage. Transmigration and environmental degradation due to soil erosion are other cardinal issues that confront the Himalayan region and its agriculture to the extent that the land holding in the hill area is smaller (700-900 $m^2$) than the national average (1370 $m^2$). In this chapter the status and issues of the Himalayan agricultural systems including agroforestry and livestock farming are discussed.

## 6.2 Methodology

In order to assess the health status of the Himalayan agro-ecosystem, the Task Force has adopted the following methodology to achieve the objective of enabling the farmers to be climate smart and the farming systems to be climate resilient in the IHR *viz*., (i) Secondary sources of information are collated to identify the data gaps, primary data collection is adopted in the project sites; (ii) Using available historical information, the datasets were simulated using available climate models to have certain projections on the variability impact of climate on agricultural and/or allied parameters so as to undertake appropriate interventions in the pilot sites (Table 6.1); (iii) Simultaneously, information on agrobiodiversity, animal/fish breeds, crop diversification, choice of crops, production, productivity, socio-economic aspects *etc*. were collected through periodical questionnaire survey; (iv) Screening and identification of local landraces of food crops and animal breeds and existing practices suitable for further improvement; (v) Identification of interventions in different sectors of agriculture such as crops, horticulture, animal husbandry, fisheries and natural resource management to enable climate resilience in the project sites (Table 6.2). While doing so, conscious effort is also taken to build the capacities of the farmers through skilling and technology demonstration processes as well. In order to assess the soil health in the Himalayan agro-ecosystems, standard analytical procedures as given in Allen *et al.,* (1974) were followed. Benefit cost ratios were estimated to arrive at the efficacy of different interventions in the project sites so as to record success stories that could be upscaled further.

**Table 6.1. List of Pilot sites and TIS under NMSHE Task Force on Himalayan Agriculture**

| Zones | Pilot Sites | Target Intervention Sites (TIS) |
|---|---|---|
| **Cold Arid Himalaya** | • Stakmo village, J & K<br>• Bodh-Kharboo, J & K<br>• Stakna, Leh, J & K | • Chushot village, J & K **(Fishery)**<br>• Khurdong, J & K **(Yak)** |
| **Lower and Middle Himalaya** | • JurKafun village, Uttarakhand<br>• Kumhali village, Himachal Pradesh | • Kotha-Tarli, Uttarakhand **(NRM)**<br>• Hartola village, Uttarakhand **(Livestock)**<br>• Doonagiri area (Dudholi and Todra village), Uttarakhand **(Fishery)**<br>• Sunkiya village, Uttarakhand **(Horticulture)** |
| **North East Himalaya** | • Lipu-Namchi village, Arunachal Pradesh<br>• Nyukmadung and Lubrang, Arunachal Pradesh<br>• Chandanpokpi village, Manipur<br>• Mawthei village, Meghalaya<br>• Bikhawthlir Village, Mizoram<br>• Hukphang village, Nagaland<br>• Phek district, Nagaland<br>• Timpyem, East Sikkim<br>• Lachen and Thangu, North Sikkim<br>• Gobinda Thakur Para,Tripura | • Mandala, Arunachal Pradesh **(Yak)**<br>• Mawthei village, Meghalaya **(Agroforestry)**<br>• Lamphelpal, Manipur **(Rice)**<br>• ICAR farm, Manipur **(Rice-Tomato)**<br>• Tamenglong, Manipur **(Orange)**<br>• Tamenglong, Manipur **(Banana)**<br>• Bishnupur, Manipur (**Vegetable)**<br>• Chandel, Manipur **(Pine)**<br>• Chandel, Manipur **(*Jhum*)**<br>• Senapati, Manipur **(Kiwi fruit)**<br>• Senapati, Manipur **(tree bean)**<br>• Senapati, Manipur **(oak)** |

***Note:*** *Pilot sites are those sites where interventions are introduced for the first time ever, while the TIS are those where specific interventions such as livestock, fishery, horticulture, natural resource management (NRM) etc. are exclusively attempted. The Task Force on Himalayan Agriculture is working on 15 pilot sites and 18 TIS.*

### *6.2.1 Indicators*

To elucidate the health of Himalayan agro-ecosystems, quantifiable indicators have been identified for periodical monitoring and are listed in the Table 6.3. Agricultural systems being smaller in unit size, unlike perennial ecosystems cannot be measured on a definite scale. However, all the system-based indicators can be monitored during every cropping season to understand the seasonality and also annual variations that would clearly elucidate the impact of the Task Force Interventions in respective sites over the years and signify the way forward for possible replications of such interventions elsewhere to enable climate resilience in agriculture *vis-a-vis* agro-ecosystem health. For instance, extent of crop diversification is an important indicator as it is a viable climate smart agriculture practice that significantly enhances crop productivity *vis-à-vis* resilience in rural smallholder farming systems.

**Table 6.2. Technological interventions in the IHR**

| | |
|---|---|
| **Natural Resource Conservation** | • Strengthening of Himalayan climatic database at micro-climate and hydrological cycle by preparing Vulnerability maps<br>• Terrace renovation and land shaping<br>• Staggered Contour trenches (SCT) for soil conservation<br>• Integrated Nutrient Management & Organic Farming<br>• Zero Tillage and In situ moisture conservation techniques<br>• Water conservation and harvesting system<br>• Drainage line treatment<br>• Contour Survey for establishment of Sloping Agricultural Land Technology<br>• Micro rain water harvesting structures and polytanks<br>• Carbon stock under different land use systems<br>• Integrated Farming System (IFS) model and intercropping in NEH<br>• Types and use of Frost in Leh and Nubra valley |
| **Crop** | • Study of yield trends of crops<br>• Successfully introduced total 128 varieties of agricultural and horticultural crops<br>• Introduction of system of rice intensification<br>• Promoting intercropping for various crops<br>• Demonstration of Azolla cultivation<br>• Planned honey bee pollination enhancing fruit/crop production<br>• Weed management techniques<br>• Integrated Pest Management<br>• Raised and sunken bed technology for crop intensification |
| **Horticulture** | • Quality planting materials<br>• Protected cultivation in poly houses<br>• Replacement of temperate crops with low chilling requirement<br>• Genetic improvement through bio-technological tools<br>• Technology demonstrated for controlling of powdery mildew and wooly apple aphis disease<br>• High density orchards |
| **Agroforestry** | • Location-specific models of agroforestry system<br>• Promoting suitable multipurpose trees for tree husbandry<br>• Alder-based rice farming<br>• Plantation of fodder and MPTs<br>• Prospecting integrating farming system models |
| **Livestock & Animal Husbandry** | • Introduction of cross bred and improved strain (16 breeds)<br>• Area-specific de-worming and vaccination<br>• Artificial insemination<br>• Value addition of yak hair fibre and yak milk<br>• Deep litter pig housing and feeding mgt.<br>• Fodder preferred by mithun<br>• Mapping of gastrointestinal parasite affected goat<br>• Feeding management in camels<br>• Promotion of backyard poultry |
| **Fishery** | • Fish hatcheries for fingerling production<br>• Rearing different types of fishes suiting to climate specific changes<br>• Community approach to cold water fishery<br>• Introduction of composite climate resilient fish farming<br>• Aquaculture suitability and fish migration maps<br>• GIS data base of fish diversity in lower and middle Himalaya |

**Table 6.3.Quantifiable Indicators to elucidate the Health of Himalayan Agro-ecosystem**

| Criteria | Indicators | Unit Scale |
|---|---|---|
| **Biological** | • Extent of Crop diversification<br>• Change (%) in cropping system<br>• Change (%) in choice of crops<br>• Net sown area<br>• Area under shifting cultivation<br>• Productivity<br>• Food Production<br>• Livestock population<br>• Disease incidence in livestock, poultry and piggery<br>• Presence (or absence) of various fish species across thermal regime | • Village<br>• Village<br>• Village<br>• Village<br>• Village<br>• Agricultural System/Village<br>• Agricultural System/Village<br>• Agricultural System/Village<br>• Village<br>• Agricultural System/Village<br>• Watershed |
| **Physicochemical** | • Soil moisture<br>• Evapotranspiration<br>• Soil erosion index<br>• Runoff loss<br>• Soil carbon sequestration<br>• Soil nitrogen | • Watershed<br>• Watershed<br>• Watershed<br>• Watershed<br>• Agricultural System<br>• Agricultural System |
| **Socio-economic** | • Number of farmers who have adopted organic farming practices<br>• % Increase in Farmer's Income<br>• Improvement in Infrastructure for irrigation and electricity<br>• Improvement in Farmer's Health<br>• Enhancement in Literacy<br>• Enhancement in On farm and Off-farm Employment<br>• Increment in Market Opportunities<br>• Any avenues for Agri-tourism | • Village/State<br>•<br>• Village/State<br>• Village/State<br>• Village/State<br>•<br>• Village/State<br>• Village/State<br>•<br>• Village/State<br>•<br>• Village/State |

Further, the physico-chemical indicators will help assess the health of IHR's soil. Overall, the health of agricultural systems is reflected not only in environmental factors but also in economic soundness and social considerations. These aspects are included as number of farmers who have adopted organic farming practices, % increase in farmer's income, improvement in irrigation infrastructure, improvement in farmer's health practices, enhancement in literacy, enhancement in on-farm and off-farm employment opportunities including market. The change in terms of percentage or actual over assessment period could showcase the impact of climate change or our effort towards achieving climate resilience.

### *6.2.2 Datasets and Analysis*

Datasets on environmental aspects are collected from meteorological departments and other sources in respective survey areas. Digital globe Quick Bird, *India WRIS* (ISRO) and ASTER satellites data are used to digitize the spatial extent of their water resources of all Indian Himalayan States. In addition, authentic documents such as Agriculture Statistics at a Glance (2016), Basic Animal Husbandry and Fisheries Statistics (2015), Intergovernmental Panel on Climate Change (IPCC), Census of India (2011), *etc*. did provide useful data. While primary data on agricultural crops and system are being collected from the pilot sites, supplementary evidences from secondary sources of information (published/unpublished) are also taken into account to develop comprehensive datasets that are monitorable. For instance, the Task Force on Himalayan Agriculture has prepared digital maps related to climate suitability of various crops, genetic resources, aquaculture suitability maps, watershed maps, socio-economic, temperature, rainfall, moisture index, mean potential evapotranspiration (PET) maps, *etc*. along with long-term yield trends of major crops in the IHR. Climate data sets are further analysed using different models and software like MIAMI model, Cropwat 8.0, Arc GIS 10.2, MOHC-HadGEM2-ES, CSIRO-MK3 6.0, NCAR-CSM4, CESM1-CAN5, ASTER, Quick Bird, *etc*. to arrive at some trends and log-term projections.

## 6.3 Status and Trends

### *6.3.1 Climatic challenges to agriculture in the Himalaya*

The effects of climate change have now become visible in hill farming. The drastic reduction in yields in certain years due to climate variation/change has been observed. Mountain people have learned to live and survive with hazards for thousands of years, but the present rate of climate change is very rapid and therefore demands attention to sustain production, productivity, protect and improve livelihood of a farming community. It has therefore now become essential to analyze economic impacts of climate change on Himalayan ecosystem, communities and livelihood of hill farmers. Some of the documented impacts on mountain agriculture that are linked with climate change in the Himalayan region are: (i) Reduced availability of water for irrigation; (ii) Extreme drought events and shifts in the rainfall regime resulting into failure of crop germination and fruit set; (iii) Invasion of weeds in the croplands and those are regularly weeded out by the farmers (*e.g., Lantana camara, Parthenium odoratum, Eupatorium hysterophorus etc.*); (iv) Increased frequency of insect-pest attacks; (v) Decline in crop yield (Negi and Palni, 2010). These factors have led to loss in agro-biodiversity and change in crops and cropping patterns.

Traditional agriculture in the Himalayan mountains has been a rich repository of agro-biodiversity and resilient to crop diseases. For example, in Uttarakhand over 40 different crops and hundreds of cultivars selected by farmers, comprising cereals, millets, pseudo-cereals, pulses and tuber crops are cultivated (Agnihotri and Palni, 2007; Maikhuri *et al.,* 1997). Mixed cropping of 12 crops (*Baranaja*) is another best example of rich agri-diversity of the region (Ghosh and Dhyani, 2004). These crops are adapted to the local environmental conditions and possess the inherent qualities to withstand the environmental risks and other natural hazards. This adaptability has ensured the food and nutritional security of the hill farmers from generations. However, the area under traditional crops has drastically declined (> 60 %) particularly during the last three decades and many of the crops are at the brink of extinction, such as *Glysine* spp., *Hibiscus sabdariffa, Panicum miliaceum, Perilla fruitescens, Setaria italica, Vigna* spp., to name a few (Maikhuri *et al.,* 2001). Deficit in food production in Kashmir region has reached 40 % in 2007 from 23 % in 1980-81 has been linked with CC (Sinha, 2007).

Climate change also leads to shift in pest incidence, migration and viability. Temperature is one of the dominant factors affecting the growth rate and development of insect pests. High summer temperatures would favour growth of temperate zone insects leading to faster development and additional generations per year (Bale *et al.,* 2002). Many of the crop species in the Himalaya vary in their response to $CO_2$. $C_3$ crops such as wheat, rice, and soybeans respond readily to increased $CO_2$ levels. Corn, sorghum, sugar cane, and millet are $C_4$ plants that follow a different photosynthetic pathway. The initial short-term studies indicated that photosynthesis is stimulated more in $C_3$ species as compared to $C_4$ species in response to $CO_2$ enrichment (Uprety and Reddy, 2008). Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, greenhouses, and poly houses.

Rise in temperature in the hill states expectedly will favour most of the vegetable and food grain crops in hills. Vegetables help in providing nutritional security and can reduce malnutrition problem prevailing in the hills (Gupta, 2003). Along with this favourable situation several negative factors will be developed such as,

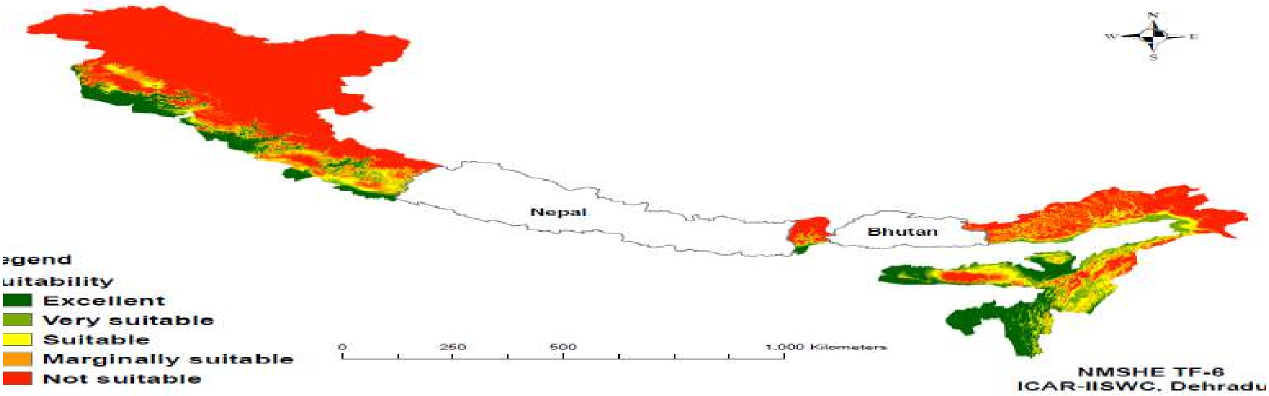
- The temperate fruit crops will be shifted to further higher altitude
- Change in preference of insect pest scenario
- Genetic erosion and loss of biodiversity
- Water scarcity

Panday *et al.* (2011; 2014 and 2016) reported decreasing trend in maximum and minimum temperatures, sunshine hours during June to September *(kharif* season), while increasing trend in maximum temperature during post-monsoon and winter and sunshine hours in winter. Warming in Nepal and on the Tibetan Plateau has been progressively greater with elevation and suggests that gradually higher warming with higher altitude is a phenomenon prevalent over the whole greater Himalayan region (New *et al.*, 2002).

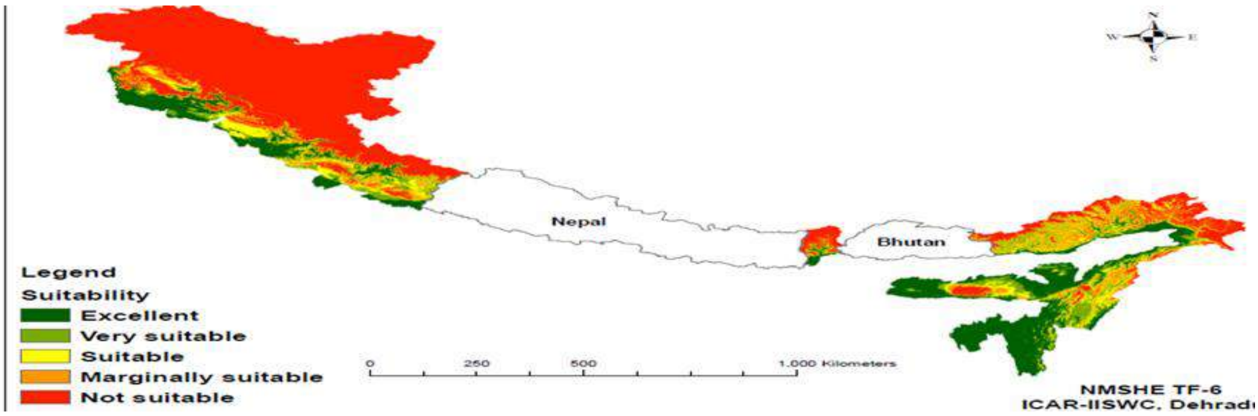
**Maize Cultivation Suitability Maps Under The Changing Climatic Scenario**

Suitability maps for cultivation of maize in IHR were prepared for 4 RCPs (Representative concentration pathways) of the year 2030 and 2050. The change in suitability of growing maize crop in terms of shift from Higher Suitable Cultivation (HSC) to Lower Suitable Cultivation (LSC) or vice versa for the year 2030 and 2050 with respect to the Base 1950-2000 are summarized below:

| Year / Change | Base vs 2030 | | | | Base vs 2050 | | | |
|---|---|---|---|---|---|---|---|---|
| | RCP 2.4 | RCP 4.5 | RCP 6.0 | RCP 8.5 | RCP 2.4 | RCP 4.5 | RCP 6.0 | RCP 8.5 |
| % of Area of IHR will be getting converted to HSC to LSC (positive Change ) | 2.4 | 2.9 | 2.6 | 2.4 | 3.2 | 3.8 | 3.4 | 3.7 |
| % of Area of IHR will be getting converted to LSC from HSC (Negative change) | 23.9 | 23.7 | 21.6 | 24.8 | 25.7 | 29.6 | 25.7 | 31.8 |
| % of Area of IHR is constant with no change in suitability | 73.7 | 73.4 | 76.0 | 72.6 | 71.1 | 66.7 | 70.9 | 64.5 |




**Base Map of climate suitability for growing maize in IHR**




**Suitability map for growing maize in IHR for 2050 under RCP 2.6**

### *6.3.2 Apple productivity trends in the IHR*

Apple is a major horticulture crop of Himalayan region. The apple productivity over the last 33 years showed a fluctuating pattern with an overall increasing trend from 1984-85 to 2016-17. The rate of increase per year was found to be 0.025 Mt/ha. An increasing trend of productivity in-spite of constant increase in temperature may have happened due to better management practices, technological advancement and farmers' adaptations to changing climatic conditions. Moreover, this might be described due to availability of appropriate chill units hours and improved and disease resistant varieties.

Sensitivity of apple crop to weather parameters (maximum temperature, minimum temperature, mean temperature and rainfall) was analyzed. The normalized yield deviations were plotted against the deviations of average annual maximum temperature, minimum temperature and mean temperature. These parameters were also analyzed for the four months from November to February. Sensitivity analysis of apple productivity with annual maximum temperature showed positive rate of 0.684 every year (Figure 6.1), which indicated that with unit increase in temperature, the yield will increase. Further, the apple yield showed an increasing sensitivity rate of 0.050 and 0.051 per year with annual minimum temperature and annual mean temperature. Similarly, sensitivity of maximum and mean temperature was done for four months (November to February) and depicted graphically which indicated that with an increase in maximum and mean temperature, the productivity showed a decreasing trend. Sensitivity analysis of apple productivity with annual rainfall revealed a positive rate of 0.048 every year, which reflected that with the unit increase in annual rainfall, the yield of apple crop will increase.

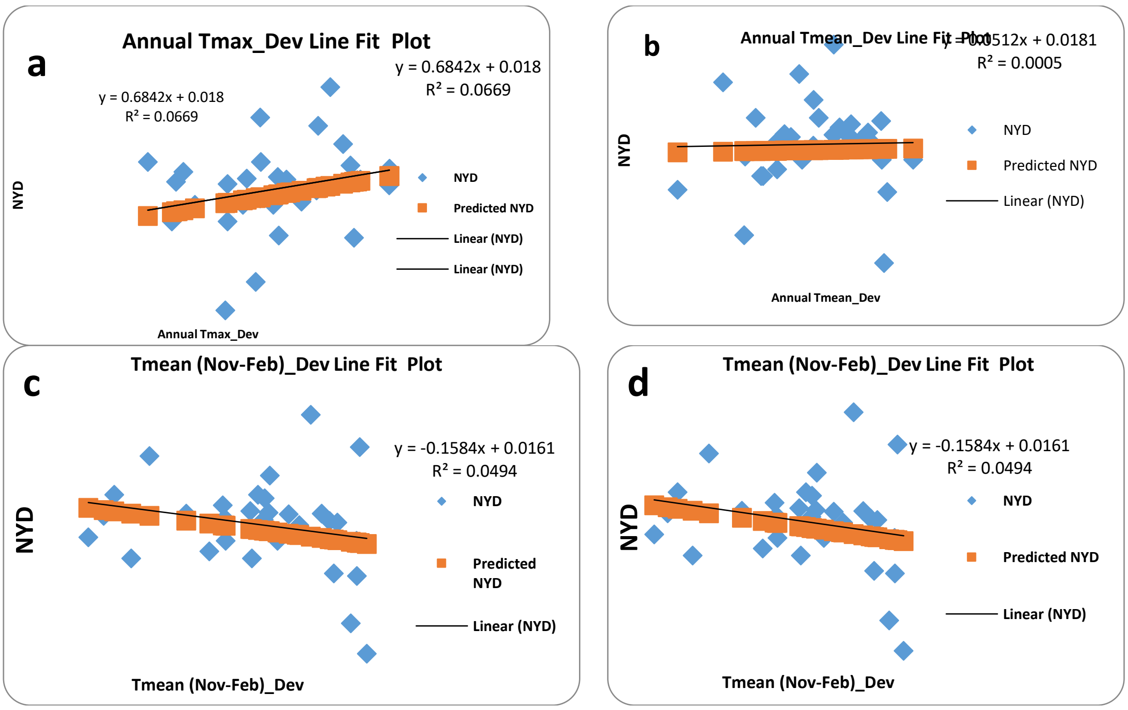



**Figure 6.1 Sensitivity of weather parameters with apple productivity (a, b, c, d)**

### *6.3.3 Degradation of native plant biodiversity due to frost heaving*

During the survey made on major pastoral systems (Nubra, Changthang, Tsokar and Leh) regions of Ladakh, frost heaves were recorded, occurring generally under conditions of water stagnation or where water would flow underneath. But wherever, the surface or subsurface flow of water has ceased, the heaves were found to have collapsed and these can be called dry formations based on the present conditions. Based on topography and soil conditions, they were grouped under upland (on the hill slopes having pediment cover), wetlands (plains), river-body heaves. At Saboo, which was a spring site with moderate slope on the foot slope of a small rocky upland, the surface had surface runoff in many channel forms (Figures 6.2 and 6.3). At Stakmo, frost heaves occurred on stones underneath the soil made the heaves longer or wider. Since water was insufficient, these were under dried condition. Since, the soil and vegetation were found desiccated, it was noted that the mass in subsided or collapsed stage and the convexity was turned into flat ones. They were sufficiently lighter (kg) with sediments turned amorphous. Keeping in view, frost heave processes were examined in detail to explore and explain the further degradation of pastoral system in Ladakh region and the status of native vegetation where these stresses have effectively affected the pasture ecology in these regions.

**Figure 6.2. Compact heaves, older formations with drainage channels at Saboo**

**Figure 6.3. Complex pattern, many in one formation and further desiccation at Stakmo**

In all pastures, continuous feeding pressure posed by nomadic livestocks and other wild animals have impacted the plant mantle significantly by 30%. Accidentally, invasive species like *Cirsium arvense* has taken over the charge and affected the temperature differences between bare soils and covered one. It has been observed in Tangtse, Durbuk Block that Cirsium has replaced the native vegetation on frost heaves and on the other hand allowed Carex species, which is considered to deplete and change the pasture ecology. Amongst these clonal communities, steppes and alpine grasslands (mostly grazed by sheep, goat and yaks) upto 5600 metres) (Jina 1995; Holzner and Kriechbaun, 1998) dominated the grasslands. Typical vegetation association at Saboo were a cluster of Kobresia, Astragulus, Glaux spp, Taraxa spp, *Cirsium arvense*, while at higher altitude at Hunder, the species were Kobresia, Phragmites spp, *Cirsium arvense* and Carex spp. In Tangtse of Changthang region, vegetation was mostly dominated tiny rosette, sedges, and other cohesive group of vegetation such as Kobresia spp, Carex, Leontopodium, Astragalus, Potentilla, Helerpestus spp, Triglochin spp., Puccinellia spp., Lancea, tibetica and Glaux maritima. In Tsokar area, Kobresia, Glaux and Astragulus, were observed on the frost heaves. Topography and elevation also showed impact on the morphological parameters of frost heaves and their habitat.

### *6.3.4 Land degradation and soil health: a major challenge to north-western Himalaya*

Soil erosion due to water is a major concern in all the Northern Himalayan states of India. Mahapatra *et al.* (2018) used the integrated approaches of geographic information system (GIS) and universal soil loss equation (USLE) for spatial and severity distribution of soil loss (Figure 6.4). Quantitative soil loss was estimated using USLE through derived information on factors of erosivity (R), soil erodibility (K), topography (LS), cover and management (C) and conservation practice (P). The computed soil loss in the state has been categorized into six classes of erosion hazards, namely very slight (<5 tonne $ha^{-1}$ $year^{-1}$), slight (5–10 tonne $ha^{-1}$ $year^{-1}$), moderate (10–15 tonne $ha^{-1}$ $year^{-1}$), moderately severe (15–20 tonne $ha^{-1}$ $year^{-1}$), severe (20–40 tonne $ha^{-1}$ $year^{-1}$), and very severe (40–80 tonne $ha^{-1}$ $year^{-1}$) (Table 6.4)

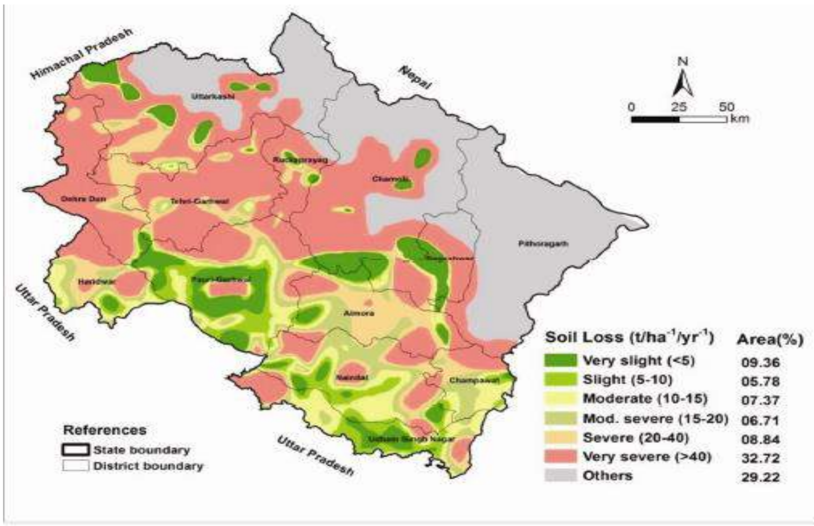



**Figure 6.4. Soil loss map of Uttarakhand (Source: Mahapatra *et al.* 2018)**

**Table 6.4. Soil erosion (soil loss) classes in Uttarakhand Source:** ***Mahapatra et al. 2018***

| **Rate of soil loss** | **Soil loss class (tonne $ha^{-1}$ $year^{-1)}$** | **Area ('000 ha)** | **Percentage** |
|---|---|---|---|
| Very slight | <5.0 | 500 | 9.36 |
| Slight | 5.0-10.0 | 309 | 5.78 |
| Moderate | 10.0-15.0 | 394 | 7.37 |
| Moderately severe | 15.0-20.0 | 359 | 6.71 |
| Severe | 20.0-40.0 | 473 | 8.84 |
| Very severe | >40.0 | 1750 | 32.72 |
| Area not covered in the soil survey | - | 1563 | 29.22 |

### Table 6.5. District-wise soil loss in Uttarakhand

| Area under different soil loss classes (tonne ha$^{-1}$ year$^{-1}$) in '000 ha (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **District** | **<5** | **5-10** | **10-15** | **15-20** | **20-40** | **>40** | **Area not surveyed** | **Total Area** |
| **Almora** | 32.7 (0.61) | 12.1 (0.23) | 21.4 (0.40) | 51.2 (0.96) | 104.5 (1.95) | 78.1 (1.46) | 0.0 (0.00) | 300.1 (5.61) |
| **Bageshwar** | 48.9 (0.91) | 5.3 (0.10) | 10.1 (0.19) | 9.3 (0.17) | 8.0 (0.15 | 93.8 (1.75) | 55.0 (1.03) | 230.4 (4.31) |
| **Chamoli** | 72.8 (1.36) | 3.1 (0.06) | 4.9 (0.09) | 5.5 (0.10) | 6.8 (0.13 | 282.2 (5.28) | 386.9 (7.23) | 762.2 (14.25) |
| **Champawat** | 8.3 (0.16) | 12.5 (0.23) | 39.0 (0.73) | 38.5 (0.72) | 23.3 (0.44) | 50.4 (0.94) | 0.0 (0.00) | 172.0 (3.22) |
| **Dehra Dun** | 8.8 (0.16) | 2.6 (0.05) | 3.0 (0.06) | 6.0 (0.11) | 32.3 (0.60) | 244.4 (4.57) | 0.0 (0.00) | 297.1 (5.56) |
| **Haridwar** | 9.0 (0.17) | 13.7 (0.26) | 43.3 (0.81) | 51.8 (0.97) | 43.9 (0.82) | 69.8 (1.30) | 0.0 (0.00) | 231.5 (4.33) |
| **Nainital** | 31.5 (0.59) | 68.7 (1.28) | 81.7 (1.53) | 78.5 (1.47) | 47.9 (0.90) | 78.1 (1.46) | 0.0 (0.00) | 386.4 (7.22) |
| **Pauri Garhwal** | 157.5 (2.95) | 103.0 (1.93) | 87.9 (1.64) | 47.2 (0.88) | 41.6 (0.78) | 125.9 (2.35) | 0.0 (0.00) | 563.2 (10.53) |
| **Pithoragarh** | 2.0 (0.04) | 0.4 (0.01) | 0.5 (0.01) | 0.3 (0.01) | 0.3 (0.01 | 27.6 (0.52) | 693.9 (12.97) | 725.0 (13.56) |
| **Rudraprayag** | 8.7 (0.16) | 3.4 (0.06) | 5.2 (0.10) | 7.4 (0.14) | 15.6 (0.29) | 114.7 (2.14) | 27.3 (0.51) | 182.3 (3.41) |
| **Tehri Garhwal** | 2.7 (0.05) | 1.2 (0.02) | 5.5 (0.10) | 20.0 (0.37) | 74.1 (1.39) | 286.0 (5.35) | 0.0 (0.00) | 389.6 (7.28) |
| **US Nagar** | 48.8 (0.91) | 78.3 (1.46) | 81.4 (1.52) | 28.7 (0.54) | 13.1 (0.25) | 54.8 (1.03) | 0.0 (0.00) | 305.2 (5.71) |
| **Uttarkashi** | 68.7 (1.29) | 4.9 (0.09) | 10.2 (0.19) | 15.4 (0.29) | 60.7 (1.13) | 243.6 (4.56) | 399.8 (7.48) | 803.3 (15.02) |
| **Total** | **500.8 (9.36)** | **309.2 (5.78)** | **394.0 (7.37)** | **359.8 (6.73)** | **472.2 (8.83)** | **1749.4 (32.71)** | **1562.8 (29.22)** | **5348.3 (100.00)** |

***(Source: Mahapatra et al. 2018)***

### *6.3.5 Status of Shifting Agriculture*

Slash-and-burn agriculture (shifting cultivation) locally known as *Jhum* is the predominant land use system of the north-east Himalayan (NEH) region. It is an age-old agricultural practice adapted to the socio-cultural framework of the local communities (ICIMOD, 2010). *Jhum* does not operate in isolation; rather it exists along with various other traditional land-use practices, namely valley rice cultivation, home gardens and traditional plantation systems. Shifting cultivation is mostly practiced in steep slopes. Land is cleared by cutting existing forests and bushes, allowing the felled biomass to dry and finally burning the biomass in the month of March/April. Traditionally the *jhum* cycle was longer than 15 years and enabled regeneration of forests before the same land was cultivated again. However, in recent decades, due to increased population pressure and socio-cultural changes in the traditional lifestyle of indigenous communities, the *jhum* cycle has been reduced to 5-6 years and in extreme cases up to 1 or 2 years (Tomar *et al.,* 2012). With this shortening of *jhum* cycle, the *jhum* sites fail to recuperate its soil fertility through the biological processes associated with re-vegetation of the area and hence have become severely degraded (Saha *et al*., 2012). The land preparation and sowing activities are done along the slopes, which promotes soil and nutrient loss. Burning of aboveground biomass increases pH and cations and decrease carbon and N content in surface soils. The soil organic carbon (SOC) content decreases after burning, because of oxidative loss of $CO_2$. At least 10 t biomass/ha is burnt in such cultivation leading to huge $CO_2$ emission levels. Reduction of *jhum* cycle is causing further land degradation as there is less time left for regaining soil fertility (Tomar *et al.,* 2012). Pangging and Arunachalam (2008) have also stated that there is an urgent need to formulate criteria and indicators (C&I) for practicing *jhum*, particularly in north-east India, with the help of a third party who shall monitor and assess the management practice of *jhum* through these standard C&I, thus helping in reducing the adverse impact of *jhum.* According to some estimates, a total of 1.02 million ha area is still under shifting cultivation in the region (Table 6.6).

**Table 6.6. Extent of the wastelands in North-East India (km$^2$)**

| States | *Jhum* | Scrub land | Degraded forest | Total |
|---|---|---|---|---|
| Arunachal Pradesh | 2039.56 (2.43%) | 2188.21 (2.61%) | 1201.68 (1.43%) | 5429.45 (6.43%) |
| Assam | 395.21 (0.5%) | 4119.79 (5.25%) | 2992.54 (3.81%) | 7507.54 (9.57 %) |
| Manipur | 471.63 (2.11%) | 4679.02 (20.95%) | 497.89 (2.29%) | 5648.54 (25.2%) |
| Meghalaya | 3268.56 (14.5%) | 540.63 (2.41%) | 69.28 (0.3%) | 3878.47 (17.2%) |
| Mizoram | 1662.08 (7.88%) | 2738.07 (12.98%) | 558.49 (2.64%) | 4958.64 (23.5%) |
| Nagaland | 2357.42(14.21%) | 2893.69 (17.45%) | 13.51(0.08) | 5264.62 (31.7%) |
| Sikkim | ---- | 20.23 (0.28%) | 61.18 (0.86%) | 81.41 (1.14%) |
| Tripura | 102.19 (0.97%) | 443.82 (4.23%) | 401.17 (3.82%) | 947.18 (9.03%) |

*Figures in parentheses represents % of TGA; Source: Wastelands Atlas of India, NRSC, Hyderabad, GOI, 2011*

Arunachalam *et al.* (2002) advocated that the initial slashing and burning becomes a huge one-time source of soil nutrients, while in agroforestry systems the litter and fine roots of the tree component continually add plant nutrients into the soil. The latter could be further improved by selecting biological nitrogen fixing tree species to promote natural nutrient cycling. Apart from bench terraces that are recommended by the state governments to enable shifting cultivators towards settled form of cultivation, the Indian Council of Agricultural Research (ICAR) is also promoting several integrated farming system (IFS) models to replace *jhum* with a sustainable, resilient and income generating agricultural practice (Singh *et al.,* 2011 ). Some of the best traditional and innovative practices have been documented from the monitoring sites, for instance, in Nagaland, include (a) Placing a fire wood/banana pseudo-stem along the field slope in a regular interval locally known as *Munkh* and (b) Planting cassava/tapioca on the field border side by side. Interesting storage practice for paddy/grains made of bamboo (locally known as *Bhu*) is used for less insect-pest infestation.

### *6.3.6 Bamboo resource in IHR*

Bamboo is one of the fastest growing plants with the ability to survive in a wide variety of climatic and edaphic conditions. It is capable of growing under soil conditions varying from organically poor to mineral rich soil and moisture to drought to flooding which makes it effective for reclaiming degraded lands. It also play important role in carbon sequestration and biodiversity conservation.

The total bamboo bearing area of the IHR is estimated to be 5.67 million hectare (Table 6.8). Arunachal Pradesh (15,125 $km^2$) has maximum bamboo bearing area followed by Manipur (10,687 $km^2$), Assam (8,955 $km^2$) and Nagaland 6,025 ($km^2$) (Table 6.8 and Figure 6.12 as compared to the estimates of FSI (2011).The total bamboo bearing area has decreased about 1167 ($km^2$). It has also been observed that bamboo-bearing area in Assam has shown highest increase of 1,717 $km^2$, followed by Manipur (1123 $km^2$). Similarly, Mizoram has shown highest decrease of 5978 $km^2$ in bamboo bearing area, followed by Sikkim (628 $km^2$). Table 6.7 reveals that the total bamboo bearing area has decreased by 1167 $km^2$ (*i.e.* 8%).

**Table 6.7. State-wise distribution of Bamboo area ($km^2$) in recorded forest area in IHR**

| States | Bamboo Bearing Area (2017) | Bamboo bearing area (2011) | Change in area with respect to ISFR 2011 |
|---|---|---|---|
| Arunachal Pradesh | 15,125 | 16,083 | -958 |
| Assam | 8,955 | 7,238 | 1,717 |
| Himachal Pradesh | 540 | 3,603 | 867 |
| Manipur | 10,687 | 9.303 | 1384 |
| Meghalaya | 5,943 | 4,793 | 1150 |
| Mizoram | 3,267 | 9,245 | -5,978 |
| Nagaland | 6,025 | 4,902 | 1123 |
| Sikkim | 553 | 1,181 | -628 |
| Tripura | 3,617 | 3,246 | -371 |
| Uttarakhand | 1,078 | 1,042 | 627 |
| West Bengal | 942 | 1,042 | -100 |
| **Total** | **56,732** | **52,384** | **-1167** |

(***Source: FSI, 2011 and 2017***)

### *6.3.7 Livestock husbandry and fish production in IHR*

India is one of the most important livestock-rearing countries in the world, with a total livestock population of 370 million head, accounting for one sixth of the cattle and a half of the buffalo population of the world. The livestock sector alone contributes nearly 25.6% of value of output at current prices of total value of output in Agriculture, fishing & forestry sector. India ranks first in goat, and sixth in sheep production. The Indian economy is predominantly agrarian in nature, and livestock plays a very vital role towards assisting the national income. In the hills, livestock farming combined with agriculture, horticulture and forestry, remains the major occupation for the rural people (Biswas *et al.,* 1994). As far as milk, egg, wool, meat and fishery is concerned, the IHR states produces 6.49%, 9.14%, 24.11%, 15.17% and 20.38% of the total country's milk, egg, wool, meat and fish production, respectively.

According to the 19$^{th}$ Livestock Census, 2012, cattle, buffalo, sheep and goat contributed to 48.17%, 3.39%, 8.14% and 31.28%, respectively of the total livestock population ofIHR . The population of cattle, buffalo, sheep and goat in IHR has decreased by 0.10% and 0.88%, 0.57% and 1.01% respectively as compared to the 18$^{th}$ Livestock Census. However, population of pig, mithun and mules have increased. Despite the decrease in cattle population, the milk production has increased. The reason behind this increment may be the introduction on modern breeds of cattle which resulted in the greater amount of milk production per animal. Along with this, the meat and egg production have also increased till 2015-16. But during 2016-17, there have been a sudden decrease in meat production in IHR, especially in the state of Uttarakhand (from 270.6 thousand tones to 28.4 thousand tonnes). Wool production is more or less same (Figure 6.5-6.9). Livestock productivity is also affected due to climate change. Available literature indicates the better ability of local breeds to cope with the changing climate compared to the hybrids (India Climate Dialogue, 2018). Therefore, unique traits of the local breeds in providing climate-resilience need to be identified and incorporated into the modern breeds.

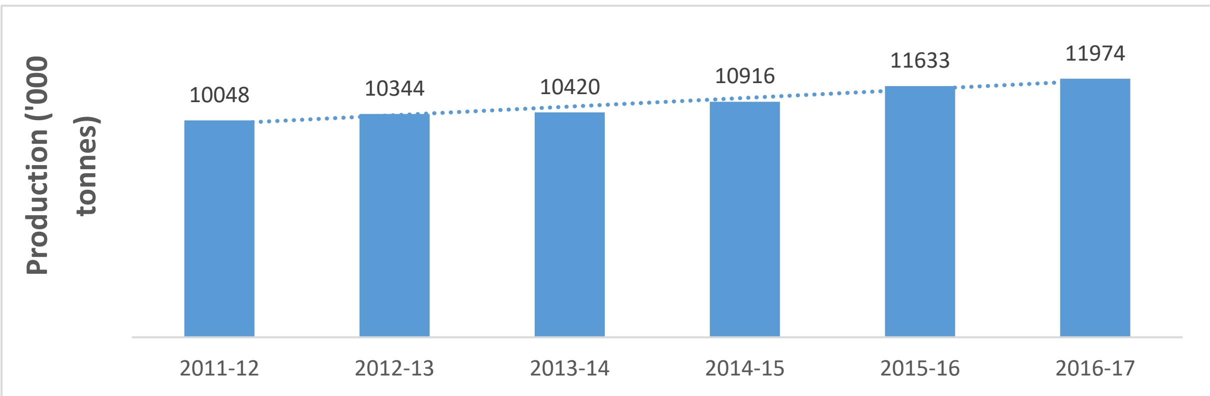



**Figure 6.5. Milk Production trend in the IHR ('000 tonnes) (Department of Animal Husbandry, Dairying and Fisheries. 2017)**

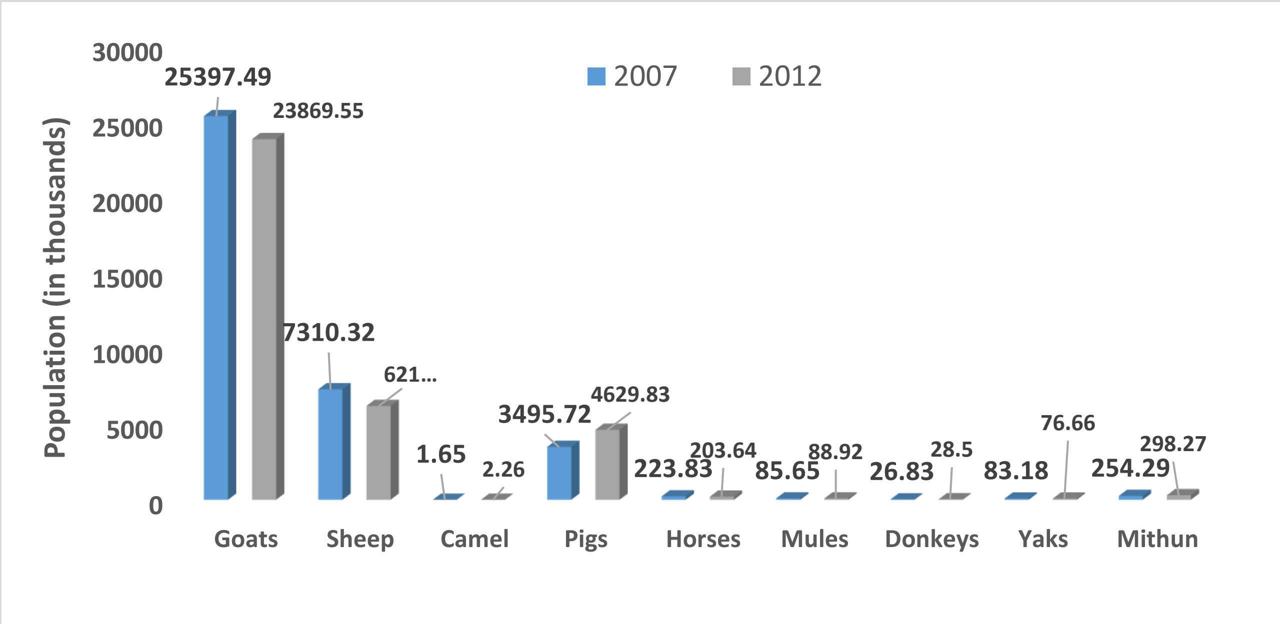



**Figure 6.6. Livestock Population (in thousands) trend in the IHR (*Department of Animal Husbandry, Dairying and Fisheries. 2015)***

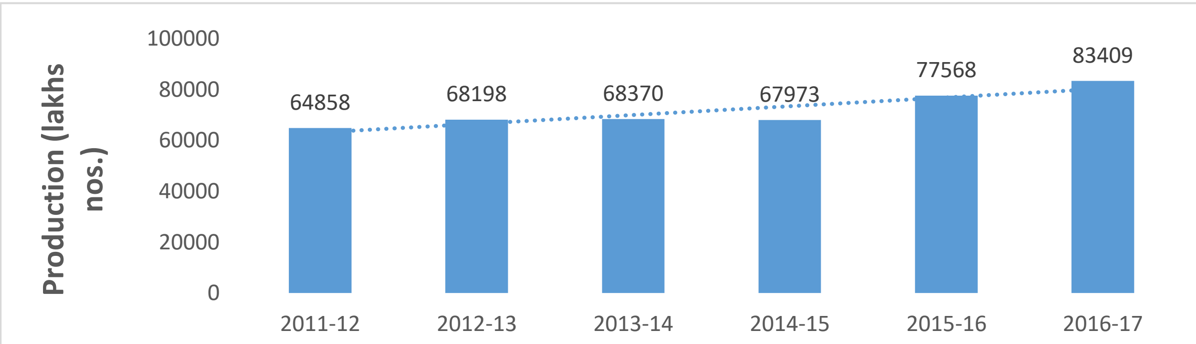



**Figure 6.7. Egg Production trend in the IHR (lakhs nos.) (***Department of Animal Husbandry, Dairying and Fisheries. 2017)*

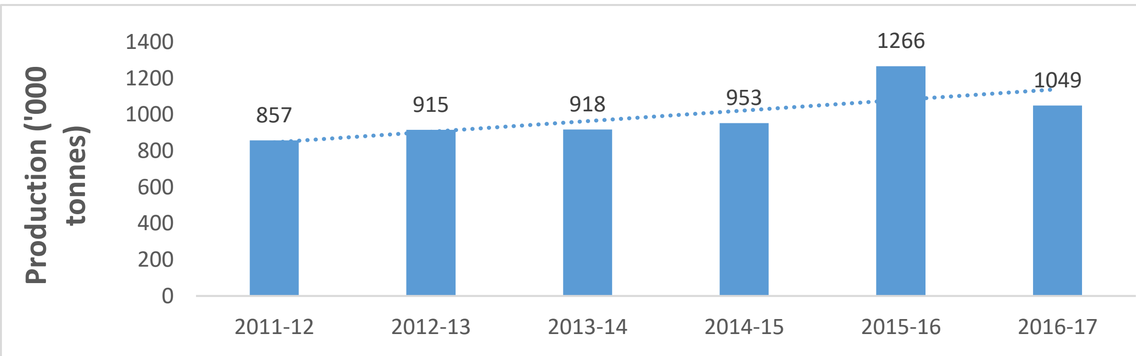



**Figure 6.8. Meat production trend in the IHR ('000 tonnes) (***Department of Animal Husbandry, Dairying and Fisheries. 2017)*

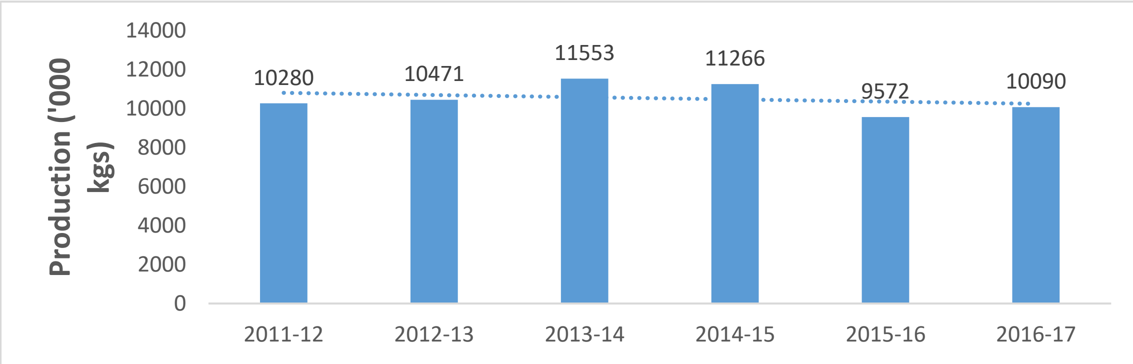



**Figure 6.9. Wool Production trend in the IHR ('000 Kgs) (***Department of Animal Husbandry, Dairying and Fisheries. 2017)*

### *6.3.8 Fishery*

Kumar et al. (2017) digitized and assessed cold-water fisheries resources using Remote sensing (RS) and Geographical Information System (GIS) for future planning. The major lotic water resources such as rivers and their tributaries having total length 10893.5 km in Jammu & Kashmir, 10464.3 km in Himachal Pradesh, 10927.9 km in Uttarakhand, 2319.5 km in Sikkim and 12351 km in Arunachal Pradesh. Total water spread area of natural and man-made lentic water resources such as lakes and reservoirs were assessed as 154248.4 ha in Jammu and Kashmir, 35481.54 ha in Himachal Pradesh, 21503.7 ha in the Uttarakhand, 1593.3 ha in Sikkim and 2808.1 ha in Arunachal Pradesh.

The freshwater ecosystem represents the most threatened of all ecosystems and many freshwater species have a very high livelihood value for local human societies in the plane as well as hill area. As per IUCN Red list 2016, some coldwater fishes such as Schiz*othorax richardsonii* (Gray, 1832); *Cyprinus carpio communis* (Linnaeus, 1758) and *Cyprinus carpio specularis* (Lacepede, 1758) were recorded under the vulnerable (VU) category. While the species like *Schizothorax progastus* (McClelland, 1839); *Nemacheilus botia* (Hamilton Buchanan, 1822); *Triplophysa microps* (Steindachner, 1866) and *Salmo trutta fario* (Linnaeus, 1758) were recorded under the Least Concern (LC) status. The other genera *viz., Schizothoraichthys; Schizopygopsis; Diptychus* and *Triplophysa* were recorded in good numbers from upland rivers and were considered on the IUCN Red list (2014) as Not Evaluated (NE) status**.** Hence, fish distribution maps were prepared in order to evaluate the fish biodiversity in the region (Figure 6.10).

Likewise, fisheries resources which are under threatened category in Garhwal and Kumaun Himalaya, are also mentioned in Table 6.8. The monitoring site (Hot spot) for the suitability of fish species for developing climate resilient aquaculture activities has been finalized as Dudhauli and Todra villages in Doonagiri area of Almora District of Uttarakhand. Fourteen farmers from each village (Total- 20) were selected to study the suitability of fish species for the development of aquaculture under climate change scenario. Twenty polytanks have been prepared for stocking of different combination of species (exotic and indigenous carp) and are being evaluated for monitoring of growth and production

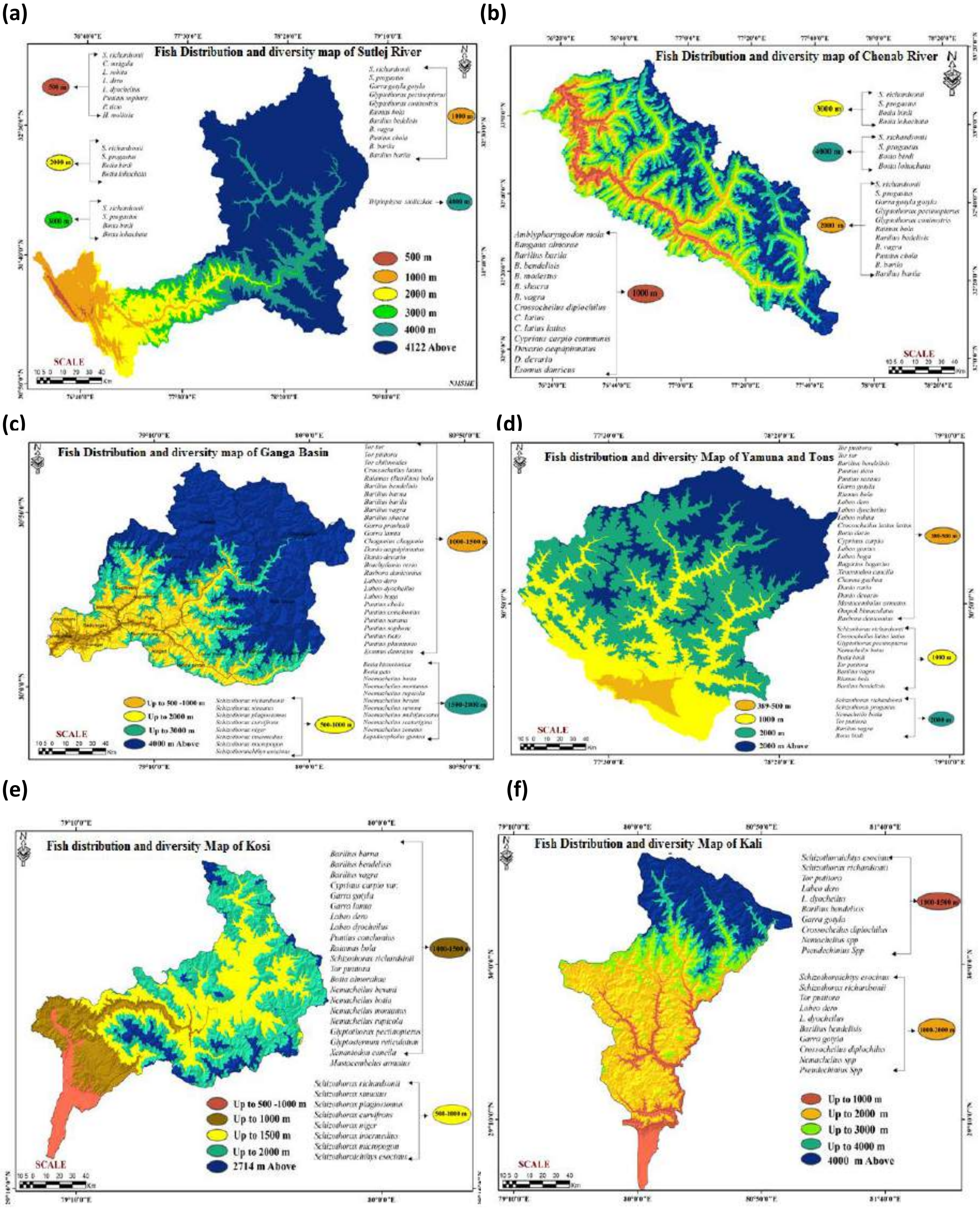



**Figure 6.10. Fish Distribution map of (a) Sutlej river, (b) Chenab river, (C) Ganga Basin, (d) Yamuna and Tons, (e) Kosi and (f) Kali rivers**

**Table 6.9. IUCN Red List status of Ichthyofaunal diversity which is threatened in Garhwal and Kumaun division (Uttarakhand)**

| Sl. No | Scientific Name | IUCN Red List Status | Elevational Range (masl) |
|---|---|---|---|
| 1 | *Schizothorax richardsonii* (Gray, 1832) | Vulnerable (VU) | 100 - 2300 |
| 2 | *Schizothorax micropogon* (Regan, 1905) | Near Threatened (NT) | 400 – 3000 |
| 3 | *Tor tor* (Hamilton, 1822) | Near Threatened (NT) | up to 1000 |
| 4 | *Tor putitora* (Hamilton, 1822) | Endangered (EN) (A4acde) | up to 1000 |
| 5 | *Tor chilinoides* (McClelland, 1839) | Vulnerable (VU) | up to 1000 |
| 6 | *Tor chelynoides* (McClelland, 1839) | Vulnerable (VU) | up to 1000 |
| 7 | *Tor tor* (Hamilton, 1822) | Near Threatened (NT) | up to 1000 |
| 8 | *Tor putitora* (Hamilton, 1822) | Endangered (EN) (A4acde) | up to 1000 |

***Source: IUCN (2016)***

## 6.4 Impact of climate change on agriculture and horticulture

Climate change in the IHR poses new challenges to agriculture and food security, especially in the Ladakh region where its impact on cereal production may be negative as high as 18.2 to 22.1%. Along with this, frequent occurrence of droughts, floods, and even flash floods in the IHR region indicates the catastrophic impacts of climate change in Himalayan region. These changes are expected to further intensify in future which are likely to reduce the agricultural productivity in the region. The already existing problems related to soil fertility and water availability are likely to amplify in a changing climate. Agriculture in Ladhak

Studies on climate change in Ladakh and on the causes of cloudburst in Leh, using weather data for the last five years (monthly temperature, rainfall, humidity and snowfall) indicate that increased temperature and hot summers in the plains lead to increased evaporation and subsequent cloud formation in the hills. When assessing the warming effects on glacier melting in the Himalaya, the role of black carbon (BC) cannot be overlooked (Ming *et al.,* 2008). In the Himalayan region, solar heating of black carbon (BC) at high elevations may be just as important as carbon-dioxide in the melting of winter snow and glaciers (Ramanathan and Carmichael, 2008). Over centuries, the farmers in Ladakh have evolved sustainable farming systems notwithstanding limited resources, amidst a climatically challenging environment. The impact of climate change over the last few years has adversely affected agriculture and livelihood security of the people, *e.g.* crops, livestock, forestry, tourism, *etc.* as well as human health. For sustainable agriculture and food security in Ladakh, it is necessary to intensify the production of main staple crops barley and wheat, and alfalfa for fodder. In addition, yield improvement of vegetables is important, as it is a beneficial source of income for the Ladakhi farmers. The local under-utilized and wild horticultural crops including medicinal and aromatic plants also warrants sufficient attention as they are rich sources of various phyto-chemical principles.

### 6.4.1 Decline in Apple Production

Various studies have reported that apple production in Kullu valley of lower middle Himalayas has significantly declined during the 1981-2000 period (Vishvakarma *et al.,* 2003; Vedwan and Rhoades, 2001). Given the strong climate dependence of agriculture in north-eastern hill regions of India, even a slight unfavourable shift in its climate could severely affect the agriculture and hence food and livelihood security of the people in this region. In fact, the signs of climate change in the Himalayan region are becoming increasingly evident in terms of rising temperature and changing rainfall pattern. Temperature is projected to rise by another 3-5$^oC$ during the latter half of this century (Cline, 2007). Summer monsoon rainfall is found to be decreasing significantly during the last century at a rate of ~11 mm/decade. Water requirement for north-east Himalayan agriculture is expected to increase from 20 $km^3$ in 2001 to 28 $km^3$ in 2025. Contrary to this, water availability shall decline in a changing climate as evident by the changing rainfall pattern, frequent droughts and recession of river-feeding Himalayan glaciers. Soil acidity, already the biggest problem in north-east Himalayan region, may further intensify under the rising atmospheric $CO_2$ concentration. Soil organic matter, a key determinant of soil health, may also suffer quantitative as well as qualitative decline under the warming atmosphere. Thus, development and implementation of various soil and water conservation and management practices need to be prioritized for climate resilient agriculture in the Indian Himalayan region.

### 6.4.2 Immediate Response to Impact of Climate Change on Himalayan Agriculture

Since climate change poses multiple biotic and abiotic challenges, a focused and long-term research is required to find solutions to the impending problems in the region. Vast diversity of local crop cultivars/germplasm can be exploited for developing crops with better tolerance to climatic changes. Further, C-sequestration potentials of traditional farming systems/land use models needs to be evaluated *vis-à-vis* that of improved farming systems/land uses. The existing technologies with potentials to provide some degree of climatic resilience also need to be made available to farming community Hence, developing improved technologies through short-term and long-term research programmes and their demonstration are important. In addition spreading awareness through demonstrations, and training to the farmers and extension personnel should be integral parts of the climate change adaptation and mitigation programmes

Considering the potential impacts of climate change on the Himalayan ecosystem, few important areas need attention and following issues are immediately required to be addressed for changing climate scenario in mountains for tackling erratic biotic and abiotic stresses:

- ***Vulnerability assessment:*** Realising the geographical diversity of the Himalayan region, block-level vulnerability assessment on a smaller geographical scale is needed so that adaptation and mitigation strategies can be implemented accordingly.

- ***Watershed approach***: Watershed approach reduces farmers' risks by integrating various enterprises, harvesting rain water and using harvested water for live saving irrigation during dry season. Percolation tanks, gully control measures, terracing *etc.* are some of the important mechanical measures in integrated watershed approach.
- ***Farming system approach***: Involving complementarities of crop-animal-horticulture-fishery-agroforestry and sound soil conservation and management practices are initiated in the hills with variation in resource endowment, preferences, and socio-economic position of the specific family.
- ***IFS models:*** In order to maximize the production per unit area, introduction of various Integrated farming system models is needed. Our Task Force intervention revealed prospective B:C ratio for different IFS models:
    - Agri-horti-duckery-fish based farming system - 3.17
    - Fish-pig-tuber crops based farming system - 1.47
    - Agri-horti-duckery-fishery based farming system (organic approach) - 2.17
    - Rice-duckery-fishery based farming system - 1.73
- ***Micro-watershed based farming system approach:*** Integrated or holistic farming with different topo-sequential cropping involving agri-horti-silvi-pastoral system and agro-pastoral based land use system was found to be most economical with effective soil and water conservation measures in the northeast.
- ***Jhum improvement approach***: Use of high-yielding stress-tolerant varieties, crop diversification, and appropriate soil treatments for fertility build up and higher productivity.
- ***Maintenance of soil fertility***: The relationship between soil erosion, nutrient, runoff losses, organic matter depletion, and beneficial effects of conservation and management practices occur simultaneously. Maintenance of optimum fertility level with application of regular doses of manure and fertilizers adjusted to soil pH 5.5 to eliminate the aluminium toxicity is recommended. Multiple cropping, inter-cropping, relay cropping, inclusion of legumes in rotation, strip cropping *etc.* and adoption of integrated nutrient management to ensure better crop productivity, besides maintaining soil fertility.
- ***Amelioration of acid soils***: Acid soils occupy nearly 81 % of geographical area in the eastern Himalayas. Acidic soils below pH 5.5 occupy around 16.2 mha area. The productivity of such acid soil is hardly about 1 t/ha. Furrow application of lime 25-500 kg/ha of high quality uniform grades /sizes at furrows every year can optimize the yields of crops in acid soils of NEH Region. Use of acid tolerant varieties and application of organic manure also improves productivity of such soils.
- ***Organic agriculture:*** The organic farming has emerged as an alternative system of farming which not only addresses the quality and sustainability concerns, but also ensures a profitable livelihood option. Creating more market opportunities for organic

products can improve the economic returns of farmers and revive the agriculture sector in the Hill regions.

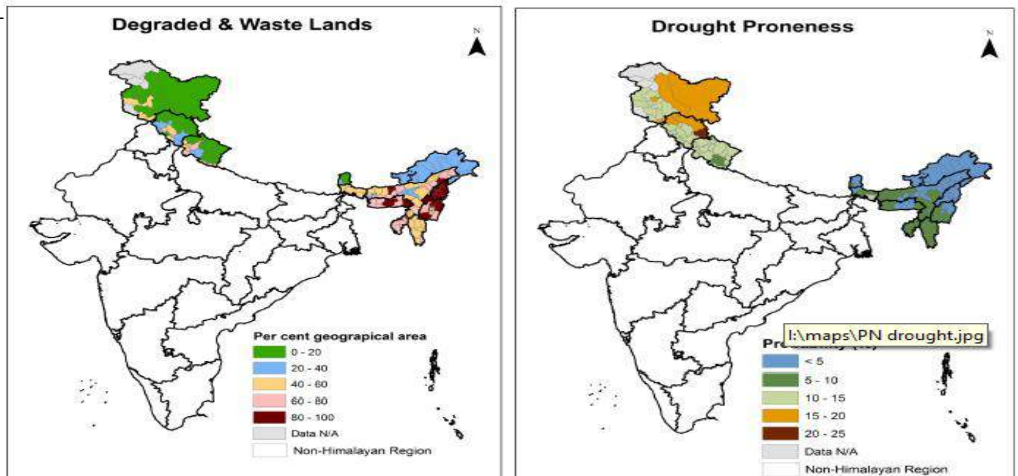
### *6.4.3 Vulnerability of Agriculture in Indian Himalayan Region to Climate Change*

Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity". In a case study of district level vulnerability assessment in the Indian Himalayan region, total 119 districts were studied. Data of 119 Himalayan districts for 37 indicators were extracted from a dataset developed with 38 indicators and 572 rural districts of India for assessing the vulnerability of Indian agriculture to climate change Rama Rao *et al.* (2016). The districts were divided into five categories, *i.e.* very low (23), low (24), medium (24), high (24) and very high (24) vulnerability. The parameters studied are given in Table 6.9.

The analysis of the degree of vulnerability (2021-50) in different states revealed that there are total 24 districts in the Himalayan region which fall under the category of very high vulnerability, *i.e*. Karbi-Anglong, Barpeta, Kulu, Kinnaur, Chamba, Simla, Bilaspur, Una, Hamirpur, Rajouri, Doda, Pulwama, Budgam, Udhampur, Anantnag, Churachandpur, Bageshwar, Tehri Garwal, Chamoli, Almora, Pithoragarh, Champawat, Rudraprayag and Uttarkashi (Figure 6.11).

**Table 6.9. Parameters studied for district level vulnerability assessment in IHR**

| Agriculture | Weather Patterns | Socio-economic |
|---|---|---|
| Net sown area, degraded wastelands,<br>net irrigated area,<br>drought proneness<br>flood proneness,<br>annual rainfall,<br>available water,<br>holding capacity of soils,<br>stage of ground water development<br>livestock population,<br>consumption of fertiliser nutrients (NPK),<br>ground water availability,<br>share of agriculture in district domestic product relative adaptive capacity, | Change in annual rainfall,<br>change in June and July rainfall<br>change in number of rainy days<br>change in maximum temperature<br>change in maximum number of hot day<br>change in number of cold days<br>change in number of frost days change in drought proneness<br>change in incidences of dry spells of more than ≥ 14 days,<br>change in 99 percentile rainfall change in number of events with >100mm rainfall within 3 consecutive days<br>change in mean maximum rainfall event as % to annual normal<br>change in mean maximum rainfall in three consecutive days as % to annual normal | Rural population density,<br>SC/ST population<br>area under small and marginal land holdings<br>relative sensitivity of the Indian Himalayan districts,<br>relative exposure of the Indian Himalayan districts,<br>rural poor,<br>agriculture workers,<br>literacy,<br>gender gap in literacy,<br>access to markets and road connectivity,<br>rural electrification, |



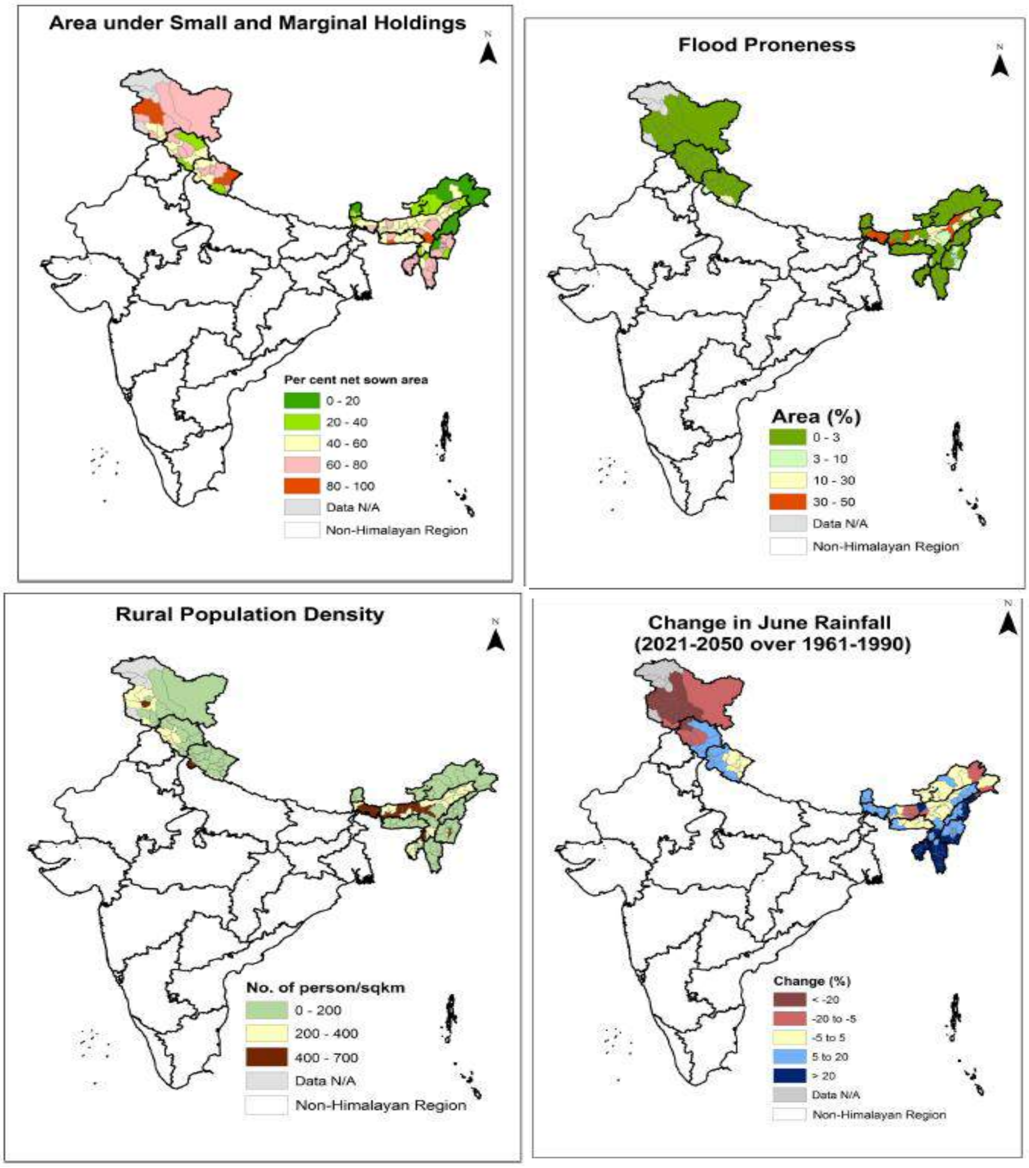
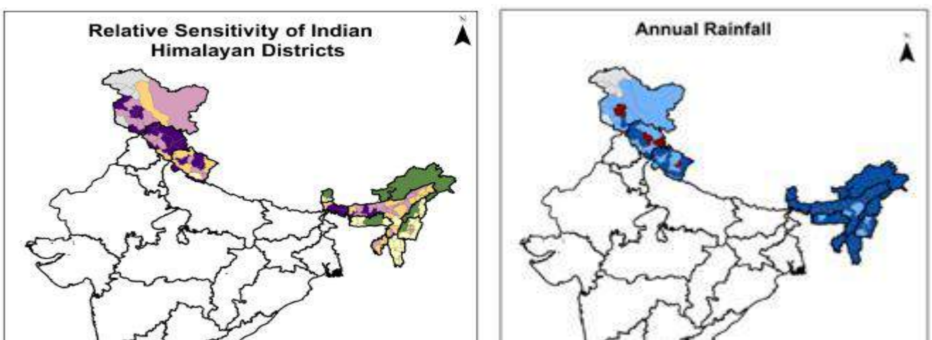



**Figure 6.11(a). Vulnerability of Agriculture in Indian Himalayan Region to Climate Change**



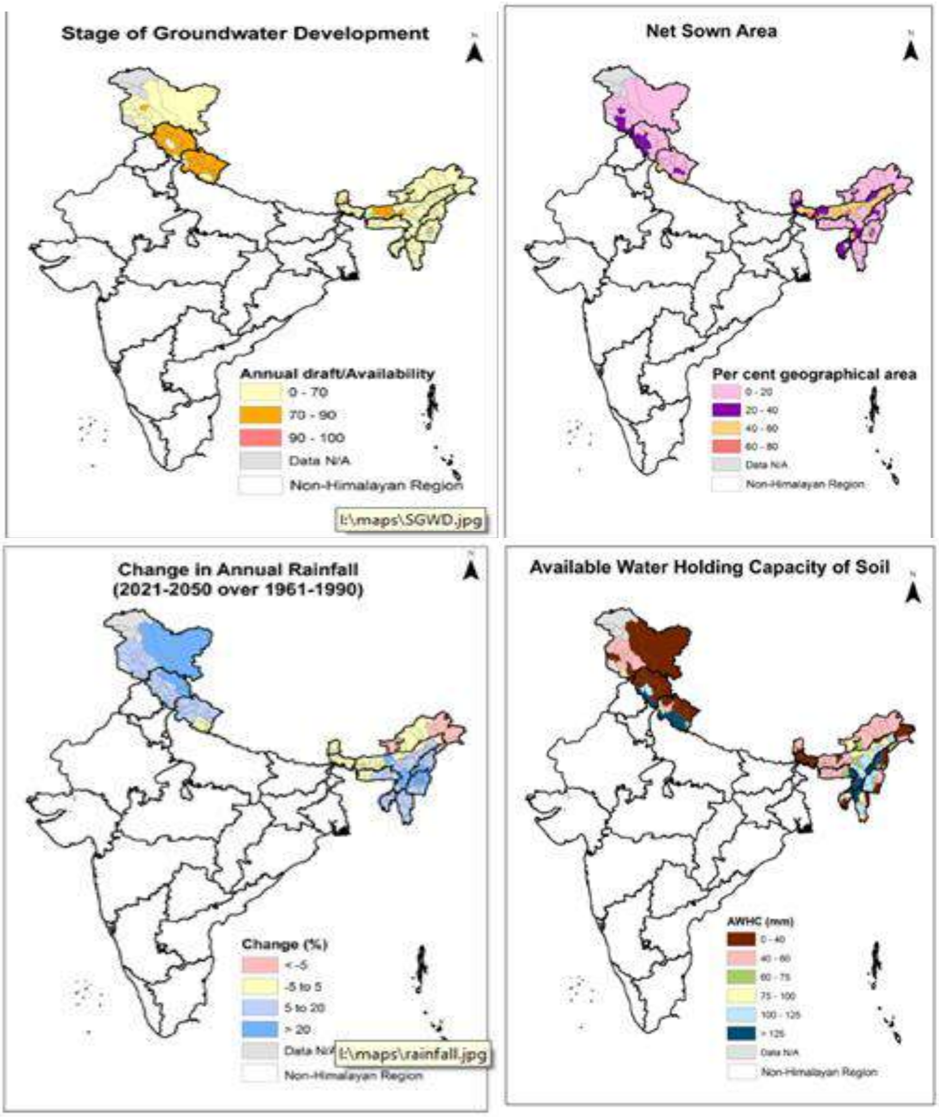



**Figure 6.11 (b). Vulnerability of Agriculture in Indian Himalayan Region to Climate Change**

#### *6.4.4 Water scarcity in the north-western Himalaya*

Long-term rainfall (low, high and variable with respect to space and time) and temperature variability is a very critical constraint for crop production in the north-west Himalayan region, where irrigation is limited to 10% cultivated area and confined only in the valleys. In many regions, a greater proportion of total precipitation appears to be falling as rain than before. As a result, snowmelt begins earlier and winter is shorter; this affects river regimes, natural hazards, water supplies, and people's livelihoods and infrastructure, particularly in basins such as the *Tarim*, which is dependent upon glacial melt in summer. The extent and health of high altitude wetlands, green water flows from terrestrial ecosystems, reservoirs, and water flow and sediment transport along rivers and in lakes are also affected (Eriksson *et al.*, 2009).

The irrigation systems have been severely affected with the rainfall becoming erratic. In all the three state (Uttarakhand, Himachal Pradesh and Jammu and Kashmir) it can be seen from the (2012-2016 data) that total amount of rainfall is decreasing year by year which could be seen in the data that has decreasing trend except some district *i.e.* Almora, Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Rudraprayag, Bilaspur, Shimla, Solan and Pulwama (*hydro.imd.gov.in*). In the Kullu valley (H.P.), it has been reported that the rainfall has decreased by about 7 cm, snowfall by about 12 cm but the mean minimum and maximum temperatures have increased by 0.25-1$^{o}$C, respectively in 1990s as compared to 1880s (Vishvakarma *et al.*, 2003). Panday *et al*. (2014 and 2016) reported decreasing trend in annual and June to September *(kharif season*) rainfall. The increasing intensity of droughts is also reported by Panday *et al.* in 2006 and 2016. However, significant increase in rainfall was noticed in Jammu and Kashmir and some parts of Indian peninsula as well (Agarwal, 2009).

Water Quality (surface water) data analysis of 122 observations points out that 5% is violating to DO, 11% is not complying to Ph, 36% is not conforming to BOD, 37% and 65% are not complying to free chlorine (FC) and total chlorine (TC), respectively, whereas conductivity is conforming to the desired levels require in riverine environment. Water quality (ground water) data analysis of 2 observations points out that all parameters *viz* pH, BOD, Conductivity, FC and TC are confirming to the desired levels as required. Water quality of river water data analysis of 114 observations points out that 5% are violating to DO, 11 % are not complying to pH, 40% are not conforming to BOD, 37% is not confirming with FC and 68% is not confirming with TC whereas conductivity is confirming to the desired levels require in riverine environment. Water quality of lake water data analysis of 4 observations points out that all parameters *viz.* DO, pH, BOD, conductivity and FC are conforming with the desired levels. In Himachal Pradesh, Water quality (surface water) data analysis of 268 observations points out that 1% is violating to DO, 2 % is not confirming to BOD, 2% and 6% are not complying to FC and TC, respectively; whereas pH and conductivity is confirming to the desired levels require in riverine environment.

Water quality (Ground Water) data analysis of 75 observations points out that 5% are not complying with the pH, 5% are not conforming to BOD. Nonetheless, conductivity, FC and TC are conforming to the desired levels as required. Water quality of river water data was analysed from 248 observations points which revealed that 3% are not complying to pH, 1% are not conforming to BOD, 2% are not conforming with FC and 6% is not conforming with TC ; whereas DO and conductivity are conforming to the desired levels require in riverine environment. Water quality of lake water data analysis of 20 observations revealed that 11% are violating to DO, 10% are not complying to pH, 20% are not conforming with BOD whereas conductivity, FC and TC is conforming with the desired levels. Whereas in Jammu and Kashmir, Water quality (surface water) data analysis of 7 observations revealed that 14% are violating to pH, 57% are not conforming to BOD whereas DO, conductivity, FC and TC are conforming to the desired levels require in riverine environment (*www.cpcb.nic.in*).

## 6.5 Policy Implications

In order to better understand the state of mountain agriculture and to improve the status of Himalayan health, there is an urgent need of few implications that may play a crucial role in making the Himalayas climate resilient and self-sufficient. Few of the policy implications are listed below:

- Conservation and crop plan for agrobiodiversity
- Ecological engineering and ecosystem restoration
- Regular mapping and assessing ecosystems/resources
- Documentation and validation of traditional knowledge system on agricultural systems management.
- District-level agriculture contingency Plan
- Disaster management plan for every district in IHR.
- Awareness and capacity building of farmers

Evidences over the past few decades have established that significant changes in climate are taking place worldwide as a result of enhanced anthropogenic activities. Despite the spectacular success of the green revolution and achieving self-sufficiency in the food production, there are increasing concerns on sustaining the pace of agricultural growth. Lack of yield breakthroughs, deteriorating soil health, ground water depletion, declining size of operational holdings and labour shortage are cited as prime reasons for slow agricultural growth. Added to these factors are the climate change and climate variability which are now emerging as major concerns.

In order to achieve climate resilience, out of 183 districts of the IHR, agricultural contingency plans *(http://agricoop.nic.in/agriculture-contingency-plan-listing*) have been prepared for 112 districts and shared with the States to guide the farmers in the present unpredictable climatic scenario. Along with this, the Task Force on Himalayan Agriculture is also deeply devoted in making the Himalayan farmers' climate smart in 15 pilot sites and 18 target intervention sites (TIS) ranging from 154 m asl in Nagaland to 4480 m *asl* in Leh. So far, the Task Force successfully introduced total 128 varieties of agricultural and horticultural crops and 16 breeds of livestock, poultry and fish breeds across the entire Indian Himalayan region at various pilot sites which has resulted in increased production and income of hill farmers. This will somewhere fill the gap between the income inequalities between hills and plains for enhancement of agricultural productivity. Simultaneously, the Task Force has conducted 235 capacity building programs. Out of these, 115 programs were conducted in north-east Himalayan region benefitting 6487 farmers, 75 programs in lower-middle Himalayan region benefitting 1390 farmers and 45 programs in cold-arid Himalayan region which benefitted 1698 farmers. In this way, the Task Force could reach out to the farmers with modern climate-resilient tools and technologies along with improved varieties of crops, poultry, fish and animal breed. Overall, the Task Force has benefitted 9575 (as on 30$^{th}$ June, 2018) Himalayan farmers through capacity building efforts.

## 6.6 Future Directions

Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture, excessive pressure on natural resources and poor coping capabilities. The negative effects of year-to-year climate variability are already evident. The country-wide rainfall deficiency during 2005-2006 has brought down the production of coarse cereals and oilseeds sharply and caused severe fodder shortage across the country, but the current year (2016-2017) estimates a record food production of 272 million tones backed by a good monsoon. Therefore, climate has become central to agricultural planning and decision making in the country, especially in the Indian Himalayas.

Following are therefore suggested future directions to enhance the health of Himalayan agroecosystem and bring in resilience to the Himalayan Agriculture:

- Crop-raiding by wild animals has emerged as a major threat to the hill agriculture which needs the immediate attention of the policy makers
- Continuous assessment and monitoring of different crops in the region for vulnerability to climatic stresses and extreme events, in particular, intra seasonal variability of rainfall
- Screening and identification of adaptive traits in traditional crop varieties and in indigenous breeds of livestock, fishery and poultry for molecular interventions to enable climate resilience
- Conservation and crop plans; land shaping and restoration of degraded land for better crop planning
- Integrated contingency plans for agriculture at district level; in order to effectively manage biodiversity, the local communities should be consulted and involved in any conservation initiatives. People should be given incentives for conservation efforts or sustainable use of bio-resources

- *In-situ* conservation of indigenous genetic resources and protection of traditional varieties involving the farming communities
- Promotion of integrated farming systems and crop diversification
- Promotion of protected cultivation and organic and herbal farming
- Value addition and Value Chain for agri-produce
- Validation of traditional knowledge system of agriculture
- Up-scaling of technologies and outputs both through Krishi Vigyan Kendras (KVKs) and the National Mission on Sustainable Agriculture (NMSA) for wider adoption by the farmers
- Information sharing between departments/agencies and state climate cells
- Establishment of long term monitoring sites and detailed studies thereof to understand climatic impacts *vis-à-vis* resilience measures.

Over all, the Himalayan agriculture is both a challenge and opportunity, as it urge us to mitigate the challenges of climatic disasters while also provisioning ecosystem services including food production through farming systems that are traditionally viable and/or being improved upon for sustainable food production in the ecologically fragile Indian Himalayan region. To enable this, it is important to integrate R&D interventions with the process of developmental outreach so as enable the farmers to be climate smart that calls for a tripartite approach - global, national and regional climate actions that foresight climate resilience *per se.* The Task Force fully recognizes the data deficiencies across agro-ecosystems in different parts of the ecologically fragile Indian Himalayan Region and attempts to generate primary information as far as possible for inclusive inference. Further, to provision a long-term monitoring of different interventions in the project sites and information generated thereof are getting shared with State Climate Cells and respective State Government Departments who would be able to take the benefit of task force interventions beyond the project period and mainstream the land use planning for agriculture development in the Indian Himalyan region.

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