



Asia-Pacific Network for Global Change Research

**Inventory of Glaciers, Glacial Lakes and the  
Identification of Potential Glacial Lake Outburst  
Floods (GLOFs) Affected by Global Warming in the  
Mountains of India, Pakistan and China/Tibet  
Autonomous Region**

**Final report for APN project 2004-03-CMY-Campbell**

J. Gabriel Campbell (Ph.D.), Director General  
International Centre for Integrated Mountain Development  
G. P. O. Box 3226, Kathmandu, Nepal, gcampbell@icimod.org

The following collaborators worked on this project:

Prof. Xin Li (Ph. D.), Cold and Arid Regions Environmental and Engineering  
Research Institute, (CAREERI), Chinese Academy of Sciences (CAS), Lanzhou,  
P. R. China, lixin@ns.lzb.ac.cn

Mr. Gong Tongliang, Bureau of Hydrology Tibet Autonomous Region, Lhasa, P.  
R. China, Gongtl@xzwater.gov.cn

Dr. Tej Partap. CSK Himachal Pradesh Agricultural University, Palampur,  
Himachal Pradesh, India, vc@cskv.hp.nic.in

Prof. Dr. B. R. Arora, Wadia Institute of Himalayan Geology (WIHG), Department  
of Science & Technology, Government of India, Dehra Dun, Uttaranchal, India,  
wihg@sancharnet.in

Dr. Badaruddin Soomro, Pakistan Agricultural Research Council (PARC),  
Islamabad, Pakistan, chair@comsat.net.pk



**Inventory of Glaciers and Glacial Lakes and the  
Identification of Potential Glacial Lake Outburst  
Floods (GLOFs) Affected by Global Warming in the  
Mountains of India, Pakistan and China/Tibet  
Autonomous Region**

**2004-03-CMY-Campbell**

**Final Report submitted to APN**

**J. Gabriel Campbell (Ph.D.)**

**Director General,**

**International Centre for Integrated Mountain Development (ICIMOD)**

**G. P. O. Box 3226, Kathmandu, Nepal, [gcampbell@icimod.org](mailto:gcampbell@icimod.org)**

**2005 July**

**©International Centre for Integrated Mountain Development (ICIMOD)**

**and**

**Asia-Pacific Network for Global Change Research (APN)**

## Overview of project work and outcomes

### Non-technical summary

The International Centre for Integrated Mountain Development (ICIMOD) undertook the project “Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of India, Pakistan and China/Tibet Autonomous Region”. ICIMOD signed the contract with the Asia - Pacific Network for Global Change” (APN) in May 2002 and with “global change SysTEM for Analysis, Research, and Training” (START) in July 2002 to carryout the APN Project 2002-15. In continuation of this, ICIMOD implemented project APN 2003-5 in the year 2003/04, and project APN 2004-03-CMY in the year 2004/05. There are co-funding from ICIMOD, UNEP/RRC-AP and the national collaborating institutions / organizations.

The main purpose of the study was to assess the threat from glacial lakes and to highlight those where GLOF events are likely to occur and cause serous damage to human life and property of India, Pakistan and China.

In the APN 2002-15 first year phase of the project, Tista Basin in Sikkim Himalaya of India, Pumqu basin in Tibet Autonomous region of PR China and Astor sub-basin in Indus basin of Pakistan were studied. In the APN 2003-05 second year phase of the project, Himachal Pradesh Himalaya of India, Poiqu and Rongxer basins in Tibet Autonomous Region of PR China, and five sub-basins (Upper Indus, Jhelum, Shingo, Shyok and Shigar) in Indus basin of Pakistan were studied. In the third year phase, APN 2004-03-CMY in the year 2004/05, Jilongcangbu, Zangbuqin, Majiacangbu, Daoliqu and Jiazhangangge basins of Tibet Autonomous Region of PR China; Uttaranchal Himalaya of India; Gilgit, Chitral, Hunza and Swat River basins of Indus Basin in Pakistan were studied in the third year phase.

This project had enabled the capacity building of the affiliated partner institutions and strengthened the collaboration between APN, START, UNEP/RRC-AP, ICIMOD, CAREERI, BHT, PARC, CSKHPAU and WIHG to continue to assist in developing regional capacity and co-operation.

### Objectives

The main objectives of the project were:

1. To understand the GLOF phenomenon by creating an inventory of existing glaciers, glacial lakes and monitoring the GLOF events on a regular basis
2. To establish an effective early warning mechanism to monitor GLOF hazards using RS and GIS in the Hindu Kush-Himalayan region
3. To develop the capacity building of national institutions to assess and monitor the GLOF phenomenon
4. To disseminate the results and outputs to the relevant organizations in the region that could make use of this information for GLOF hazard prevention and mitigation planning

### Amount received for each year supported and number of years supported

APN Project 2002-15	US \$77,340
APN Project 2003-05	US\$ 75,000
APN Project 2004-03-CMY Year 3	US\$ 67,000

## **Participating Countries**

India, Pakistan and China

## **Work undertaken**

1. Acquisition of satellite images of Landsat TM and ETM+, IRS 1C LISS3, CBERS and ASTER.
2. Acquisition of topographic maps.
3. Acquisition of other necessary data (e.g. meteorological and hydrological data).
4. Development of training materials for the inventory and study of glaciers and glacial lakes using Geographic Information System (GIS) and Remote Sensing (RS).
5. Institutional capacities strengthened by training the participants of collaborating institutions and agencies.
6. Provided GIS & RS software and other technical supports to the participating institutions and agencies.
7. On-the-job trainings to the professionals of the participating countries in their own institutions and agencies for the inventory of glaciers and glacial lakes using RS & GIS.
8. Preparation of digital database of glaciers, glacial lakes and potential dangerous glacial lakes (GLOFs) of Ganges basin in Tibet Autonomous Region of PR China; Sikkim Himalaya, Himachal Pradesh Himalaya and Uttaranchal Himalaya of India; Indus Basin in Pakistan, using RS & GIS technologies.
9. Documentation of glacial lake outburst floods hazard risks and potential impacts.
10. Reports preparation in collaboration with the participating institutions and agencies.
11. Preparation of interactive multi-media CD-ROMs with the comprehensive technical reports with digital database, maps and other information.
12. Presentation of the project activities and finding of the study in the various workshops/seminars/conferences to help to create wider awareness among governments, development agencies and the public of GLOF phenomena and hazards, locally/ regionally/ internationally.
13. GLOF workshops in each of the participating countries for the presentation of the studies to disseminate/discuss/interact with the related institutions / organizations

## **Results**

1. Digital satellite images of Landsat7ETM+, IRS 1C LISS3, CBERS and ASTER of the project areas.
2. Digital topographic maps at the scale of 1:500,000 of the study areas.
3. Upgraded/established the RS & GIS facilities to the institutions and agencies.
4. Training manual and materials for the inventory and study of glaciers and glacial lakes using GIS and RS.
5. Strengthened institutional capacities by giving training cum workshop at ICIMOD to the collaborating institutions and agencies of China, India and Pakistan in RS & GIS technology for the inventory of glaciers and glacial lakes
6. Trained six professionals of Bureau of Hydrology Tibet (BHT), TAR PR China on-the-job trainings at ICIMOD from 9<sup>th</sup> August to 23<sup>rd</sup> August 2003.
7. Trained professionals of the participating countries through on-the-job trainings in their own institutions and agencies for the inventory of glaciers and glacial lakes using RS & GIS.
8. Digital database of glaciers and glacial lakes of Himachal Pradesh Himalaya of India, sub-basins of Ganges of Tibet Autonomous Region of PR China and Indus basin of Pakistan.

## 9. Documentation of glaciers, glacial lakes and potential GLOFs and associated hazards.

### **Relevance to APN scientific research framework and objectives**

As a result of global climate change many of dangerous glacial lakes formed in the region, with direct impacts on terrestrial change and human vulnerability and adaptation. By the study of GLOFs, three of APN's priority topics are addressed: (1) Changes in Terrestrial Ecosystems, (2) Human Dimensions of Global Change and (3) Climate Change and Variability. These are high priority areas for research and documentation, especially in the HKH region. Advanced scientific knowledge of potential GLOF hazards, capacity building among local institutions and agencies, and the linking of this knowledge to policy makers and planners is, therefore, of immense importance to the lives of millions of mountain dwellers and their downstream neighbors.

### **Self evaluation**

In the period of three years, a systematic study on the inventory of glaciers and glacial lakes of this part was completed using Remote sensing satellite and topographic data and a comprehensive database was developed. A semi-automatic methodology for inventory of glaciers and glacial lakes was developed for future glacial monitoring. One of the major objectives of this study was to identify areas where GLOF events could pose a potential threat in the near future. Based on the detailed criteria the potentially dangerous lakes were identified which needs to be monitored in future. These results thus provide the basis for the development of a monitoring and early warning system and for the planning and prioritization of disaster mitigation efforts that could save many lives and properties situated downstream as well as guide line for infrastructure planning.

The series of reports with information on the glaciers, glacial lakes and GLOFs of the HKH region in compatible and comparable format begin as the filling up this pressing need. Taken together, the database will greatly enhance the ability of global and regional climate researchers, national policy makers, land-use planner and water resource planners, as well as the general public, to understand and mitigate GLOF-associated hazards, thus linking science to policy. The project provided an opportunity for professionals and institutions among partners / collaborators / of the region and beyond to learn more about the methodology and related activities to build up their confidence for the future work for further cooperation.

Distributions of the reports and database in the interactive CD-ROMs and posting those also in WebPages and the workshops disseminated to wider audiences and also created much awareness.

### **Potential for further work**

1. Further institutional capacity strengthening by advanced on-the-job training to the participants of the collaborating institutions and agencies.
2. Acquisition of necessary materials (e.g. satellite images, maps, data, etc.) of higher resolutions / details.
3. Preparation of digital database of glaciers and glacial lakes at higher resolutions / details and also for other basins in India, China (Tibet region), Pakistan using RS & GIS technologies.
4. Establish detailed analytical protocols and systems to identify 'hot-spots' (existing and potentially dangerous glacial lake hazards), and to regularize GLOF hazard studies.
5. Analyse and synthesise the database to locate hot-spots and potential GLOF circumstances, and dissemination of the results to the concerned agencies.
6. Conduct rapid environmental change assessment (RECA) studies on GLOF hazard

risks and potential impacts in detail.

7. Prepare analytical studies and briefing papers for policy-makers/planners, to be presented in regional/international workshops, conferences and publications potential GLOF hazards and risks and their potential impacts and mitigation, through the participating country organizations.
8. Comprehensive communication and dissemination plan developed and implemented based on the results and outputs of database analysis, to strengthen policy and planning within relevant agencies, and to inform research institutions and the public, nationally and regionally.

## **Publications**

### **Reports:**

Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of Himalayan Region:

1. Pumqu Basin
2. Astor Basin
3. Tista Basin
  
4. Himachal Pradesh Himalaya: India
5. Poiqu and Rongxer basins: Tibet Autonomous Region, PR China
6. Upper Indus, Jhelum, Shingo, Shyok and Shigar basins: Pakistan Himalaya
  
7. Pumqu (Arun), Rongxer (Tama Koshi), Poiqu (Bhote-Sun Koshi), Jilongcangbu (Trisuli), Zangbuqin (Budhigandaki), Majiacangbu (Humla Karnali), Daoliq and Jiazhangangge Basins: Tibet Autonomous Region, People's Republic of China
8. Indus Basin: Pakistan Himalaya
9. Uttaranchal Himalaya: India

### **Inter-active CD-ROMS:**

Inventory of glaciers and glacial lakes and the identification of potential glacial lake outburst floods (GLOFs) affected by global warming in the mountains of Himalayan region:

1. Pumqu Basin
2. Astor Basin
3. Tista Basin
  
4. Himachal Pradesh Himalaya: India
5. Poiqu and Rongxer basins: Tibet Autonomous Region, PR China
6. Upper Indus, Jhelum, Shingo, Shyok and Shigar basins: Pakistan Himalaya
  
7. Pumqu (Arun), Rongxer (Tama Koshi), Poiqu (Bhote-Sun Koshi), Jilongcangbu (Trisuli), Zangbuqin (Budhigandaki), Majiacangbu (Humla Karnali), Daoliq and Jiazhangangge Basins: Tibet Autonomous Region, People's Republic of China
8. Indus Basin: Pakistan Himalaya
9. Uttaranchal Himalaya: India

### **Training Manual:**

Spatial Data Input, Attribute Data Handling and Image Processing for the Inventory of Glaciers and Glacial Lakes and Identification of Potential Glacial Lake Outburst Floods.

### **Websites:**

1. <http://www.icimod-gis.net/glof/glof.php> Pumqu Basin - China (2003) OR [http://www.icimod-gis.net/china/pumqu\\_basin/start.htm](http://www.icimod-gis.net/china/pumqu_basin/start.htm)
2. <http://www.icimod-gis.net/glof/glof.php> Astor Basin - Pakistan (2003) OR [http://www.icimod-gis.net/pakistan/astor\\_basin/start.htm](http://www.icimod-gis.net/pakistan/astor_basin/start.htm)
3. <http://www.icimod-gis.net/glof/glof.php> Sikkim Himalaya (2003) OR [http://www.icimod-gis.net/india/sikkim\\_glof/start.htm](http://www.icimod-gis.net/india/sikkim_glof/start.htm)
4. <http://www.icimod-gis.net/glof/glof.php> Himachal Pradesh - India (2004) OR [http://www.icimod-gis.net/india/hp\\_glof/start.htm](http://www.icimod-gis.net/india/hp_glof/start.htm)
5. <http://www.icimod-gis.net/glof/glof.php> Poiqu and Rongxer Basin - China (2004) OR [http://www.icimod-gis.net/china/china\\_2004/start.htm](http://www.icimod-gis.net/china/china_2004/start.htm)
6. <http://www.icimod-gis.net/glof/glof.php> Upper Indus, Jhelum, Shingo and Shigar Basins - Pakistan (2004) OR [http://www.icimod-gis.net/pakistan/pakistan\\_2004/start.htm](http://www.icimod-gis.net/pakistan/pakistan_2004/start.htm)
7. <http://www.icimod-gis.net/glof/glof.php> Pumqu, poiqu, Rongxer, Jilongcangbu, Zangbuqin, Majiacangbu, Daoliqu and Jiazhangange Basins - China (2005) OR [http://www.icimod-gis.net/china/china\\_2005/start.htm](http://www.icimod-gis.net/china/china_2005/start.htm)
8. <http://www.icimod-gis.net/glof/glof.php> Indus Basin - Pakistan (2005) OR [http://www.icimod-gis.net/pakistan/indus\\_glof/start.htm](http://www.icimod-gis.net/pakistan/indus_glof/start.htm)
9. <http://www.icimod-gis.net/glof/glof.php> Uttaranchal Himalaya - India (2005) OR [http://www.icimod-gis.net/india/ua\\_glof/start.htm](http://www.icimod-gis.net/india/ua_glof/start.htm)

### **References**

Inventory of glaciers and glacial lakes and the identification of potential glacial lake outburst floods (GLOFs) affected by global warming in the mountains of Himalayan region: - Pumqu Basin; Astor Basin; Tista Basin; Himachal Pradesh Himalaya: India; Poiqu and Rongxer basins: Tibet Autonomous Region, PR China; Upper Indus, Jhelum, Shingo, Shyok and Shigar basins: Pakistan Himalaya; Pumqu (Arun), Rongxer (Tama Koshi), Poiqu (Bhote-Sun Koshi), Jilongcangbu (Trisuli), Zangbuqin (Budhigandaki), Majiacangbu (Humla Karnali), Daoliqu and Jiazhangange Basins: Tibet Autonomous Region, People's Republic of China; Indus Basin: Pakistan Himalaya; Uttaranchal Himalaya: India.

### **Acknowledgments**

Thanks are due to Mr. Sombo T. Yamamura, Director, Mr. Yukihiro Imanari, Executive Manager, Ms. Jody Chambers, Programme Manager, Mr. Martin Rice, former Programme Manager, Communications and Development, Dr. Linda Anne Stevenson, Programme Manager, Ms. Sirijit Sangunurai, Programme Fellow, Mr. Tomoya Motoda, Technical Assistant, Mr. Toshiaki Mitani, Administrative Manager, Ms. Kanako Taguchi, Administrative Assistant, of Asia-Pacific Network for Global Change Research (APN) for their continuous support in the implementation of the project.

I would like to express sincere thanks to Prof. Roland Fuchs, Director, Dr. Hassan Virji, Deputy Director, Ms. Kathleen Landauer, Programme Associate Ms. Alix Cotumaccio, Programme Associate and Dr. Yna Calimon, former Programme Associate of International global change SysTem for Analysis, Research, and Training (START) Secretariat for providing grant and their timely and strong support and advice while implementing the project.

I would also like to express sincere thanks to: Prof. Xin Li, CAREERI; Mr. Gong Tongliang, BHT; Dr. Tej Partap, CSKHPAU; Dr. B. R. Arora, WIHG; Dr. Badaruddin



# **Technical Report of APN Project 2004-03-CMY**

## **Preface**

The glaciers are nature's valuable source of fresh water for drinking water supply, agricultural, industrial and hydropower developments for present and future needs of millions of people living in the down stream. These frozen reservoirs release large amounts of ice melt water to many of the major rivers of this region. The glaciers, many of which consist of a huge amount of perpetual snow and ice, are found to create many glacial lakes. However, these glaciers are retreating due to accelerated global warming. Rapid accumulation of water in these glacial lakes, particularly in those adjacent to receding glaciers, can lead to a sudden breach of their unstable moraine 'dams'. The resultant discharges of huge amounts of water and debris – a *Glacial Lake Outburst Flood or GLOF* – often have catastrophic effects downstream. Knowledge of this resource seems an outstanding requirement for future planning for water resources and flood hazards.

## **Table of Contents**

	<b>Page number</b>
<b>Preface</b>	<b>1</b>
<b>Table of Contents Page</b>	<b>2</b>
<b>1.0 Introduction</b>	<b>3</b>
<b>2.0 Methodology</b>	<b>4</b>
<i>Materials</i>	<b>6</b>
<i>Inventory Methodology and Criteria for Hot-spot Identification</i>	<b>7</b>
<i>Brief description of glacier inventory</i>	<b>7</b>
<i>Brief description of glacial lake inventory</i>	<b>8</b>
<i>Criteria for the identification of potential glacial lake outburst floods</i>	<b>10</b>
<i>Use of Remote Sensing and Geographic Information System</i>	<b>12</b>
<b>3.0 Results &amp; Discussion</b>	<b>16</b>
<b>4.0 Conclusions</b>	<b>23</b>
<b>5.0 Future Directions</b>	<b>24</b>
<b>References</b>	<b>25</b>
<b>Appendix</b>	<b>40</b>
<u><b>Conferences/Symposia/Workshops</b></u>	
<u><b>Funding sources outside the APN</b></u>	
<u><b>Glossary of Terms</b></u>	
<u><b>Hand-out of Power Point Slides as an example</b></u>	

## 1.0 Introduction

The glaciers are the frozen water reserves in the high altitude Hindu Kush-Himalaya (HKH) and are one of the most important natural resources in the region. They act as a source of life by providing fresh water to hundreds of millions of people living in the mountainous region as well as in the adjoining plains. Melt water released by the glaciers as well serves as the perennial source for most of the Himalayan river systems. The streams originating from these glaciers are also the source of energy for hydroelectric power plants, which in turn irrigates agricultural lands in the command area especially during the summer period when it is most needed, and also provide water for various other uses. In this way to a major extent these glaciers determine the socio-economic activity in this part of the Indian subcontinent. While the total number of glaciers in the region is still unknown, this study has revealed the existence of glaciers and glacial lakes in a large scale.

The glaciers are also the repositories of information for exploring Quaternary climate changes, as they remain sensitive to global temperature conditions as indicated by their continuous retreat. For example global warming influences the glacier retreat as recorded from many parts of the world including the Himalaya. The fast melting of glaciers and their retreating trend particularly after the industrial revolution is a major concern to scientists and planners in the region. The fast retreat of glaciers is not only decreasing the channel discharge in long term but also brings about large sediment loads and cause flashfloods downstream and has direct bearing on the life of hydropower projects and socio-economic implications for the population living in valleys and downstream area.

Therefore, proper understanding of the status and health of these glaciers is very important for long-term planning in the area. Surging, retreating and fast melting of glaciers in these high mountains expose terminal moraines and create glacial lakes at the terminus of end moraines. Rapid accumulation of water in glacial lakes particularly those adjacent to receding valley glaciers can lead to a sudden breaching of the unstable debris dam which shall ultimately cause glacial lake outburst floods (GLOF) and is a matter of concern for economic and life losses in the river valleys.

In the HKH region many glacial lakes are known to have formed in the last half a century and a number of GLOFs have been reported in the region in the last few decades, particularly from the eastern sector of the region. These GLOFs have resulted in many deaths as well as the destruction of property and infrastructures. It is most likely that the lakes at risk are situated in remote inaccessible and uninhabited areas and their impact in the event of an outburst influences the larger region of downstream.

Knowledge of glacier storage and transfer of ice down slope and area altitude relations of ice cover are integral parts of the water balance. Knowledge of glacier activity is also required, in relation to glacier hazards such as ice dams and surges. To systematically identify and make an inventory of different types of glaciers and to estimate the ice reserves in the HKH region, a detail inventory of glaciers in the basin wise at the larger scale is necessary.

The main objectives of the present study is to assure that mountain inhabitants in the HKH region enjoy safe and sustainable livelihoods through a better understanding of environmental hazards associated with Mountain Glaciers and glacial lakes, with which to address environmental policy, planning and impact/risk mitigation:

- by understanding the GLOF phenomenon by creating an inventory of existing glacial lakes and monitoring the GLOF events on a regular basis using geography information system and remote sensing technology
- by establishing an effective early warning mechanism to monitor GLOF hazards using RS and GIS in the Hindu Kush-Himalayan region
- by developing the capacity building of national institutions to assess and monitor the GLOF phenomenon
- by disseminating the results and outputs to the relevant organizations in the region that could make use of this information for GLOF hazard prevention and mitigation planning.

As a result of global climate change many of dangerous glacial lakes formed in the region, with direct impacts on terrestrial change and human vulnerability and adaptation. By the study of GLOFs, three of APN's priority topics are addressed: (1) Changes in Terrestrial Ecosystems, (2) Human Dimensions of Global Change and (3) Climate Change and Variability. These are high priority areas for research and documentation, especially in the HKH region. Advanced scientific knowledge of potential GLOF hazards, capacity building among local institutions and agencies, and the linking of this knowledge to policy makers and planners is, therefore, of immense importance to the lives of millions of mountain dwellers and their downstream neighbors.

## 2.0 Methodology

The present study of glaciers and glacial lakes of Hindu Kush – Himalayan region at medium to large scale in uniform and comparable format is first of its kind. A beginning has been made to document glaciers, glacial lakes and potentially dangerous glacial lakes in the HKH region. To accomplish the study the steps taken to the methodology for database development to dissemination of the results are shown in the Flowchart. The flowchart can be divided into different steps as of collection of material (literature, topographic maps, aerial photographs, satellite images etc.); processing and data capturing; Analysis and report writing; and dissemination of results in the form of report, CDs, and workshops.

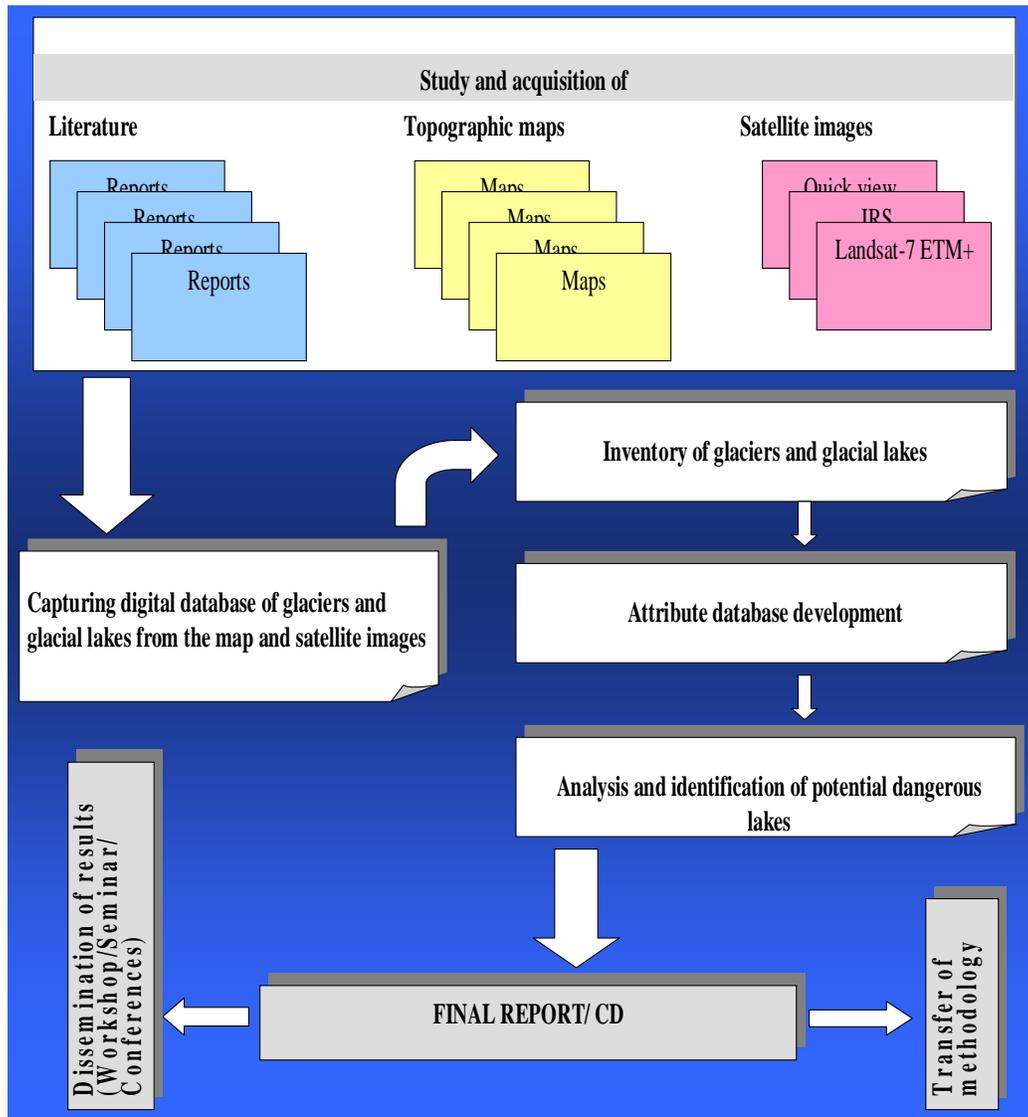


Figure: The flow diagram of methodology used for inventory.

**Materials:**

The basic materials used for the compilation of an inventory of glaciers and glacial lakes are different type of satellite images, topographic maps and published maps, field report and available literatures. Medium to high resolution satellite images of different dates are more useful in the inventory of glaciers and glacial lakes. The combination of satellite remote sensing data and the digital elevation model (DEM) were also used for better interpretations and more accurate results for the inventory of glaciers and glacial lakes in the three dimension geographic information system platform.

The topographic maps at better/larger scales (scale, 1:50,000) are mostly difficult to acquire and to be used. The projection parameter are used from the maps at the regional scales (1:250,000) and the digital topographic map (ARC digitized Raster Graphics (ADRG)), in the orientation of UTM zones and WGS84 datum published in late 90's by the National Imagery and Mapping Agency (NIMA) and Defense Mapping Agency (DMA) of the U.S. Government at the scale of 1:500,000. DEM were also prepared based on NIMA maps data

Aerial photographs of the region were not available for the use.

Satellite images were obtained for the latest dates with no or minimum cloud cover and also least snow cover. For the present study Landsat 7 ETM+, IIRS LISS3 images, ASTER images were used.

The projection parameters of the topographic maps were identified and used as references in the geo-referencing of the satellite images.

Digital elevation data generated by Shuttle Radar Topography Mission (SRTM) were used for the 3D applications. The SRTM digital elevation models are being developed from the SRTM C-band radar observations for selected regions to satisfy the needs of NASA related projects and to speed the evaluation of acquisition and processing and applications algorithms.

Integrated Land and Water Information System (ILWIS) ver.3.2 for Windows was used for the spatial and attribute database development and analysis. ILWIS for Windows is an object oriented image processing and Geographic Information System. Analysis and modeling in a GIS requires input of relevant data sets. Delineation of all the glaciers and glacial lakes was done on the Geo-referenced satellite images. All the glaciers and glacial lakes were numbered and their attributes were marked.

The satellite images were geo-referenced on the coordinate system of Universal Transverse Mercator (UTM). For an example, coordinate system parameters for the satellite images used are as follows:

- |                        |                                     |
|------------------------|-------------------------------------|
| • Projection:          | Universal Transverse Mercator (UTM) |
| • Ellipsoid:           | WGS 84                              |
| • Datum:               | WGS 1984                            |
| • Ellipsoid Parameters |                                     |
| a =                    | 6378137.000                         |

1/f =	298.257223563
• Northern Hemisphere	Yes
• Minimum X	221473.969
• Minimum Y	3300590.500
• Maximum X	513943.969
• Maximum Y	3488960.500
• Zone	44, 45 and so on

The extent of minimum and maximum of X and Y may varies according to the area.

***Inventory Methodology and Criteria for Hot-spot Identification:***

The methodology for the mapping and development of inventory database of the glaciers are similar to the inventory of glaciers and glacial lakes carried out in Nepal and Bhutan by Mool et. al, 2001 and based on instructions for compilation and assemblage of data for the World Glacier Inventory (WGI), developed by the Temporary Technical Secretary (TTS) at the Swiss Federal Institute of Technology, Zurich (Muller et al. 1977). And the methodology for the inventory of glacial lakes is based on that developed by the Lanzhou Institute of Glaciology and Geocryology, the Water and Energy Commission Secretariat, and the Nepal Electricity Authority (LIGG/WECS/NEA 1988). The same methodology of inventory of glaciers and glacial lakes were adopted for the whole Hindu Kush - Himalayan region under the present studies.

The inventory of glaciers and glacial lakes has been systematically carried out on the basis of drainage basins identified in the satellite images and verified on the topographic maps. The satellite images were geo-referenced which can be used around the scale of 1:50,000. The inventory of glaciers and glacial lakes were carried out and verified in the published Topographic maps of different scales (mostly 1:50,000).

The following sections described the process of compilation of the inventories for both the glaciers and glacial lakes have been carried out.

***Brief description of glacier inventory***

The inventory of glaciers is based on topographic maps and satellite images. All the satellite images area geo-referenced incorporating all the projection parameters of the topographic maps to make the image compatible with the topographic maps. Digital topographic maps published by NIMA and DMA of the US Government in January 1996 were used in the areas where the topographic maps are unavailable.

For the inventory of glaciers, the areas are divided into major river basins. The aerial extension of the glaciers is determined by using remote sensing satellite image and Geographic Information System (GIS). To estimate the ice reserves, it is of an utmost necessity to have the mean thickness of the glaciers. Since the mean glacier thickness data are not available, it has been estimated using the equation developed for the Tianshan Mountains (Chaohai Liu and Liangfu Ding 1986) and applied in Nepal and Bhutan (Mool et al., 2001).

$$H = -11.32 + 53.21F^{0.3}$$

Where,

H = mean ice thickness in meter and F = area of glacier in square kilometer

The ice reserves were estimated by multiplying the mean thickness by the area of the glacier.

For convenient the glaciers are classified morphologically on the basis of the World Glacier Monitoring Service (WGMS) defined by Muller et al. 1977. The glaciers are divided into different classes, combining Digit 1 of 'primary classification' and Digit 2 of 'form'. Generally, six types of glacier are observed in HKH region namely Mountain, Valley, Cirque, Niche, Ice caps, and Ice aprons. Mountain glaciers are the dominant ones and by profile due to steepness of the slope, they are of hanging nature. Other glaciers, except for Valley glaciers, generally fall into the category of Mountain glaciers but the thickness of ice is comparatively low. The number of Valley glaciers is comparatively low but the corresponding area and ice reserves are higher than those of Mountain glaciers. The area and ice reserves of the Valley glaciers are generally large owing to the fact that the ice thickness increases with increase in the area of the glacier.

The Mountain glaciers are uncertain or miscellaneous, compound basins, compound basin, or simple basin in the form of a hanging glacier. The Mountain glaciers sometimes join with the Valley glaciers and make a big mass of ice. The major source of nourishment is snow and/or drift snow. Ice caps, Cirque, Niche, and Ice apron type glaciers are other types of hanging Mountain glaciers, but they are considered to be of a different type due to their significance in size, shape, form, and ice thickness.

The Valley type glaciers are characterized by compound basins, compound basin, and simple basin. They are mainly nourished by snow and drift snow at the headwater and by snow and ice avalanches at the lower valley. The adjoining part of the Valley glacier at the headwater is characteristically a Mountain glacier, but due to its continuation into a Valley glacier, the whole ice mass will be considered as a Valley glacier. This is the reason for higher area of Valley glaciers than that of the Mountain glaciers. The longitudinal profile of the Valley glacier from crown to toe shows an even or regular shape. As the headwater is steeper and has a gentle slope in the lower reaches, the profile makes the curve concave upward. Due to the gentle slope at the lower reaches and the accumulation of debris derived from the headwater, the glacial lakes develop in the form of supra glacial or moraine dammed. Generally, the stability of glacial lakes is poor and there is always the chance of avalanches from Mountain glaciers, which may break the damming material and cause GLOFs.

### ***Brief description of glacial lake inventory***

In the Himalayan region, major rivers are originating from glaciers and larger portion of the freshwater resources are locked up in ice and snow. As mentioned earlier, during the last few decades there has been a rapid retreat of glaciers which has created many precarious glacial lakes in the Hindu Kush-Himalayan region. A glacial lake is defined as water mass existing in a sufficient amount and extending with a free surface in, under, beside, and/or in front of a glacier and originating from glacier activities and/or retreating processes of a glacier. The isolated lakes found in the mountains and valleys far from the

glaciers may not have a glacial origin. Due to the rapid rate of ice and snow melt, possibly caused by global warming, accumulation of water in these lakes has been increasing rapidly in Himalaya. The isolated lakes above 3,500 masl are considered to be the remnants of the glacial lakes left due to the retreat of the glaciers.

The lakes located at the snout of the glacier are mainly dammed by the lateral or end moraine, where there is high tendency of breaching. Such lakes could be dangerous as they may hold a large quantity of water. Breaching and the instantaneous discharge of water from of such lakes can cause flash floods enough to create enormous damage in the downstream areas. In order to assess the possible hazards from such lakes it is therefore essential to have a systematic inventory of all such lakes formed at the high altitudes. This is feasible by identifying them initially through satellite images (and aerial photographs, if available) and to assess their field setting subsequently. Besides making a temporal inventory, a regular monitoring of these lakes is also required to assess the change in their nature and aerial extent.

The lakes are classified into Erosion, Valley trough, Cirque, Blocked, Moraine Dammed (Lateral Moraine and End Moraine Dammed lakes), and Supraglacial lakes.

#### *Erosion lakes*

Glacial Erosion lakes are the water bodies formed in a depression after the glacier has retreated. They may be Cirque type and trough Valley type lakes and are stable lakes. These Erosion lakes might be isolated and far away from the present glaciated area.

#### *Supraglacial lakes*

The Supraglacial lakes develop within the ice mass away from the moraine with dimensions of 50 to 100 meters. These lakes may develop in any position of the glacier but the extension of the lake is less than half the diameter of the Valley glacier. Shifting, merging, and draining of the lakes are the characteristics of the Supraglacial lakes. The merging of lakes results in expansion of the lake area and storage of a huge volume of water with a high level of potential energy. The tendency of a glacial lake towards merging and expanding indicates the danger level of the GLOF.

#### *Moraine Dammed lakes*

In the retreating process of a glacier, glacier ice tends to melt in the lowest part of the glacier surrounded by Lateral Moraine and End Moraines. As a result, many supraglacial ponds are formed on the glacier tongue. These ponds sometimes enlarge to become a large lake by interconnecting with each other and have a tendency to deepen further. A Moraine Dammed lake is thus born. The lake is filled with melt water and rainwater from the drainage area behind the lake and starts flowing from the outlet of the lake even in the winter season when there is minimum flow.

There are two kinds of moraine: an ice-cored moraine and an ice-free moraine. Before the ice body of the glacier completely melts away, glacier ice exists in the moraine and beneath the lake bottom. The ice bodies cored in the moraine and beneath the lake are sometimes called dead ice or fossil ice. As glacier ice continues to melt, the lake becomes deeper and wider. Finally, when ice contained in the moraines and beneath the lake completely melts away, the container of lake water consists of only the bedrock and the moraines.

*Blocking lakes*

Blocking lakes are formed through glacier and other factors, including the main glacier blocking the branch valley, the glacier branch blocking the main valley, and the lakes through snow avalanche, collapse and debris flow blockade.

*Ice-dammed lakes*

An Ice-dammed lake is produced on the side(s) of a glacier, when an advancing glacier happens to intercept a tributary/tributaries pouring into a main glacier valley. As such, an Ice core-dammed lake is usually small in size and does not come into contact with glacier ice. This type of lake is less susceptible to GLOF than a moraine dammed lake. A glacial lake is formed and maintained only up to a certain stage of glacier fluctuation. If one follows the lifespan of an individual glacier, it is found that the Moraine Dammed glacial lakes build up and disappear with a lapse of time. The moraine dammed lakes disappear once they are fully destroyed or when debris fills the lakes completely or the mother glacier advances again to lower altitudes beyond the moraine-dam position. Such glacial lakes are essentially ephemeral and are not stable from the point of view of the life of glaciers. Generally, moraine dammed lakes pose a threat in the basin.

***Criteria for the identification of potential glacial lake outburst floods***

In general, based on geo-morphological characteristics, glacial lakes can be grouped into three types: glacial Erosion lakes, glacial Cirque lakes, and Moraine Dammed lakes. The former two types of glacial lakes occupy the lowlands or emptying cirques eroded by ancient glaciers. These glacial lakes are more or less located away from present-day glaciers and the downstream banks are usually made of bedrock or covered with a thinner layer of loose sediment. Both of these glacial lakes do not generally pose an outburst danger. On the other hand, the Moraine Dammed glacial lakes have the potential for bursting. A standard index to define a lake that is a source of potential danger because of possible bursting does not exist.

Moraine Dammed glacial lakes, which are still in contact or very near to the glaciers, are usually dangerous. The present study defines all the lakes formed by the activity of glaciers including in the past as 'glacial lakes'. Moraine Dammed glacial lakes are usually dangerous. These glacial lakes were partly formed between present-day glaciers and Little Ice Age moraine. The depositions of Little Ice Age moraines are usually about 300 years old, form high and narrow arch-shaped ridges usually with a height of 20–150 m, and often contain dead glacier ice layers beneath them. These End Moraines are loose and unstable in nature. The advance and retreat of the glacier affect the hydrology between the present-day glacier and the lake dammed by the moraines. Sudden natural phenomena with a direct effect on a lake, like ice avalanches or rock and Lateral Moraine material collapsing on a lake, cause moraine breaches with subsequent lake outburst events. Such phenomena have been well known in the past in several cases of Moraine Dammed lakes, although the mechanisms at play are not fully understood.

*Criteria for Identification*

The criteria for identifying the potentially dangerous glacial lakes (hot-spots) are based on field observations, processes and records of past events, geo-morphological and geo-technical characteristics of the lake and surroundings, and other physical conditions.

#### *Rise in Lake Water Level*

In general, the lakes, which have a volume of more than 0.01 km<sup>3</sup> are found to have past events. A lake, which has a larger volume than this, is deeper, with the deeper part near the dam (lower part of lake) rather than near the glacier tongue, and has rapid increase in lake water volume is an indication that a lake is potentially dangerous.

#### *Activity of Supraglacial lakes*

As time passes, groups of closely spaced Supraglacial lakes of smaller size at glacier tongues merge and form bigger lakes. Using temporal satellite images, one can identify the successive merging of Supraglacial lakes and the formation of a bigger lake. These activities of Supraglacial lakes are indications that the lakes are becoming potentially dangerous.

#### *Position of Lakes*

The potentially dangerous lakes are generally at the lower part of the ablation area of the glacier near to the End Moraine, and the mother glacier should be sufficiently large to create a potentially dangerous lake environment. Regular monitoring needs to be carried out for such lakes with the help of multi-temporal satellite images, aerial photographs, and field observations.

In general, the potentially dangerous status of Moraine Dammed lakes can be defined by the conditions of the damming material and the nature of the mother glacier. The valley lakes with an area bigger than 0.1 km<sup>2</sup> and a distance less than 0.5 km from the mother glacier of considerable size are considered to be potentially dangerous. Cirque lakes even smaller than 0.1 km<sup>2</sup> associated (in contact or distance less than 0.5 km) with steep hanging glaciers are considered to be potentially dangerous. Even the smaller size steep hanging glacier may pose a danger to the lake.

#### *Dam Conditions*

The natural conditions of the moraine damming the lake determine the lake stability. The lake stability will be less if the moraine dam has a combination of the following characteristics:

- narrower in the crest area
- no drainage outflow or outlet not well defined
- steeper slope of the moraine walls
- ice cored
- very tall (from toe to crest)
- mass movement or potential mass movement in the inner slope and/or outer slope
- breached and closed in the past and refilled again with water
- seepage flow at moraine walls

#### *Conditions of Associated Mother Glacier*

Generally, the bigger Valley glaciers with tongues reaching an elevation of below 5,000 masl have well-developed glacial lakes. Even the actively retreating and steep hanging glaciers on the banks of lakes may be a potential cause of danger. The following general characteristics of associated mother glaciers can create danger to Moraine Dammed lakes:

- hanging glacier in contact with the lake,
- bigger glacier area,
- fast retreating,
- debris cover at glacier tongue area,
- steep gradient at glacier tongue area,
- presence of crevasses and ponds at glacier tongue area,
- toppling/collapses of glacier masses at the glacier tongue, and
- ice blocks draining to lake.

#### *Physical Conditions of the Surrounding Area*

Besides moraines, mother glaciers, and lake conditions, and other physical conditions of the surrounding area as given below may also cause the lake to be potentially dangerous:

- potential rockfall/slide (mass movements) site around the lake which can fall into the lake suddenly,
- snow avalanches of large size around the lake which can fall into the lake suddenly,
- neo-tectonic and earthquake activities around or near the lake area,
- climatic conditions of successive years being a relatively wet and cold year followed by a hot and wet or hot and dry year,
- very recent moraines damming the lake at the tributary glaciers that used to be just a part of a former complex of Valley Glacier, middle moraines as a result of the fast retreat of a complex mother Valley Glacier, and
- sudden advance of a glacier towards the lower tributary or the mother glacier having a well-developed lake at its tongue

#### *Use of Remote Sensing and Geographic Information System*

One of the main objectives of the present study is to develop a digital database of glaciers and glacial lakes using Geographic Information Systems (GIS). A digital database is essential for the monitoring of glaciers and glacial lakes and to identify the potentially dangerous lakes. GIS is the most appropriate tool for spatial data input and attributes data handling. Basin-wise spatial database of glaciers and glacial lakes are presented in the results together with their attribute information. The spatial and attribute information generated and also provided in web-pages can be visualized and utilized in any GIS platforms, eg. ArcView or through free ware software like ArcExplorer.

Creating inventories and monitoring of the glaciers, glacial lakes, and extent of GLOF impact downstream can be accomplished quickly with reasonable accuracy using remote sensing techniques. The multistage-approach using remotely sensed data and limited field investigation increase the ability and accuracy of the work. Visual and digital image analysis techniques integrated with techniques of GIS are very useful for the study of glaciers, glacial lakes, and GLOFs. For the present inventory, satellite images mostly of Landsat-7 ETM+ and supplemented with limited relevant ground maps and reports were used to identify and distinguish the glaciers and glacial lakes.

A scene of a Landsat-7 data gives a synoptic view of an area of 183 km by 170 km of the earth's surface sensed by the American Landsat satellite from an altitude of 705 km, sun-synchronous orbit at an inclination of 98.2 degrees, imaging the same 183 km swath of the earth's surface every 16 days. The Landsat-7 ETM+ sensor is a nadir-viewing, seven-band plus multi-spectral scanning radiometer that detects spectrally filtered radiation from several portions of the electromagnetic spectrum. Nominal ground sample distances or pixel sizes include 30 meters each for the six visible, near-infrared, and short-wave infrared bands, 60 meters for the thermal infrared band, and 15 meters for the panchromatic band. The individual bands are Band 1 (0.45–0.52µm), Band 2 (0.53–0.60µm), Band 3 (0.62–0.69µm), Band 4 (0.78–0.90µm), Band 5 (1.57–1.78µm), and Band 7 (2.10–2.35 µm) with the spatial resolution of 30m in the visible, near infrared and middle infrared bands, and Band 6 (10.45–11.66 µm) in the far infrared with low gain and high gain bands with 60m resolution. Band 1, 3, 5, and 6 are same in TM and ETM+. Band 2, 4, and 7 are slightly different and the visible panchromatic mode is only available in ETM+. The TM and ETM+ sensors greatly facilitate the multi-temporal data availability (repeated coverage of 16 days) for studying the temporal changes of glaciers, lakes, and other features.

The spatial resolution of LISS3 of the IRS satellite series and XS of the SPOT satellite series are greater than that of LANDSAT TM. With a greater number of spectral bands and spatial resolution of 30 by 30m close to the former two data types, cloud free LANDSAT TM or ETM+ data are equally good for the inventory and evaluation of glaciers, glacial lakes, and GLOFs in the medium scale (1:100,000 to 1:25,000).

Table : Wavelength ranges of the optical sensor system of Earth resources satellites used in the study.

Satellite system Optical sensor system	LANDSAT 4/5 MSS	LANDSAT 4/5 TM	SPOT XS	IRS-1C/1D LISS-III
Blue		0.45–0.52 µm (B1)		
Green	0.50–0.60 µm (Ch1 or B4)	0.53–0.61 µm (B2)	0.50–0.59 m (XS1)	0.52–0.59 µm (B2)
Red	0.60–0.70 µm (Ch2 or B5)	0.62–0.69 µm (B3)	0.62–0.68 µm (XS3)	0.62–0.68 µm (B3)
NIR	0.70–0.80 µm (Ch3 or B6)	0.78–0.90 µm (B4)	0.78–0.88 µm (XS3)	0.77–0.86 µm (B4)
NIR	0.80–1.10 µm (Ch4 or B7)			
IIR		1.57–1.78 µm (B5)		1.55–1.75 µm (B5)
IIR		2.10–2.35 µm (B7)		
IIR (MIR)				
ThIR		10.45–11.66 µm (B6)		
FIR				

To identify the individual glaciers and glacial lakes, different image enhancement techniques are useful. With different spectral band combinations in false colour composites (FCCs) and in individual spectral bands, glaciers and glacial lakes can be identified and studied using the knowledge of image interpretation keys: colour, tone,



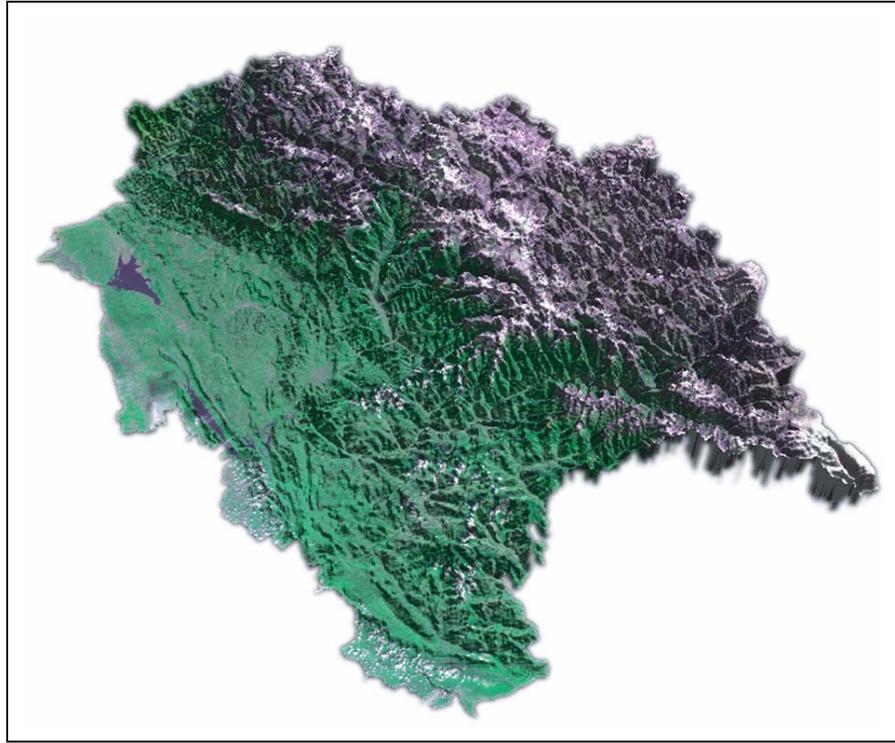


Figure: IRS 1D LISS 3 R5G4B3 draped over the DEM of Himachal Pradesh

### 3.0 Results & Discussion

In this three years project, the area covered for the study of glaciers and glacial lakes are all the ten sub-basins of Indus River in Pakistan, all sub basins of Ganges in Tibet Autonomous Region of the Peoples' Republic of China, and Tista River basin, Himachal Pradesh and Uttaranchal Himalaya of India.

In Pakistan 5218 glaciers with the glacier area coverage of around 15040 sq km and 2420 lakes were identified and mapped. Among the identified lakes 52 lakes are classified from which the potential threat of glacial lake outburst floods.

In India Himalaya, the study area covers only the Tista River basin (Sikkim Himalaya), Himachal Pradesh (HP) and Uttaranchal (UA) Himalayas. The Tista River basin covers only 285 glaciers with the glacier area about 576 sq km and the glacial lakes 266 and 14 potentially dangerous glacial lakes. Though the area is comparatively very small but the number of lakes and potential GLOF is very high compared to other study region. The Himachal Pradesh region holds 2554 glaciers with the glacier area of about 4160 sq km and 229 lakes including 22 potential GLOF. The Uttaranchal Himalayan region holds 1439 glaciers with the glacier area of about 4060 sq km, though in Uttaranchal Himalayan region 127 lakes are identified from the satellite images but it need further detailed study at larger scale images to identify lakes to be categorize for potential GLOF.

In Tibet Autonomous Region of the Peoples' Republic of China altogether 8 sub-basins of Ganges is identified. A total of 1578 glaciers with a glacier area of about 2864 sq km were mapped which was about 2906 sq km in 1990's. Altogether 824 lakes were identified and among that 77 lakes are categorized in the potential GLOF.

The number of glaciers, glacier area, ice-reserve, number of glacial lakes, total lake area and potential GLOF in sub-basin wise is summarized in the Table.

These glaciers and glacial lakes are the major source of water supply for agricultural, industrial, and hydropower development in the mountainous region. On the other hand the GLOFs often have catastrophic effect that resulted in heavy loss of human lives and their property, destruction of infrastructure, and damage to crop fields and forests. These valuable resources and hazards have never been systematically studied and harnessed in the past. Knowledge of this resources and hazards seems to be an outstanding requirement for future planning of water resources and flood hazard monitoring system.

Table: Summary of glaciers, glacial lakes and potentially dangerous glacial lakes of the studied areas in the Hindu Kush Himalaya Region

S. No	River Basins	Glaciers			Glacial Lakes		
		Nr.	Area (km <sup>2</sup> )	Ice Reserve (km <sup>3</sup> )	Nr.	Area (km <sup>2</sup> )	Potential danger
<b>Pakistan</b>							
<b>1</b>	<b>Indus River Basin</b>						
	Swat	233	223.55	12.221	255	15.86	2
	Chitral	542	1903.67	258.817	187	9.36	1
	Gilgit	585	968.1	83.345	614	39.17	8
	Hunza	1050	4677.34	808.794	110	3.21	1
	Shigar	194	2240.08	581.27	54	1.09	0
	Shyok	372	3547.84	891.8	66	2.68	6
	Indus	1098	688	46.38	574	26.06	15
	Shingo	172	36.91	1.009	238	11.59	5
	Astor	588	607.03	47.931	126	5.52	9
	Jhelum	384	148.18	6.943	196	11.78	5
	<b>Total</b>	<b>5218</b>	<b>15040.7</b>	<b>2738.51</b>	<b>2420</b>	<b>126.35</b>	<b>52</b>
<b>India</b>							
	<b>Tista River</b>	<b>285</b>	<b>576.51</b>	<b>64.78</b>	<b>266</b>	<b>20.20</b>	<b>14</b>
	<b>Himachal Pradesh</b>						
1	Beas	358	758.18	76.4	74	237.70	10
2	Ravi	198	235.21	16.88	45	1.32	1
3	Chenab	681	1704.70	187.66	53	3.90	6
4	Satluj	945	1217.70	94.45	50	136.62	3
5	Sub-basins	372	244.79	11.96	7	0.18	2
	<b>Total</b>	<b>2554</b>	<b>4160.58</b>	<b>387.35</b>	<b>229</b>	<b>379.72</b>	<b>22</b>
	<b>Uttaranchal</b>						
1	Yamuna	124	172.98	17.88	20	0.17	0
2	Bhagirathi	393	1034.30	143.41	32	0.44	0
3	Alaknanda	540	1675.24	191.36	54	1.37	0
4	Kali	382	1177.52	122.78	21	0.51	0
	<b>Total</b>	<b>1439</b>	<b>4060.04</b>	<b>475.43</b>	<b>127</b>	<b>2.49</b>	<b>0</b>
<b>China</b>							
	<b>Ganges Basin</b>						
1	Pumqu	900	1330.60	130.95	383	52.01	38
2	Poiqu	151	231.58	19.02	91	15.66	9
3	Rongxer	206	224.09	30.44	183	8.40	16
4	Jilongcangbu	180	418.61		72	3.32	2
5	Zangbuqin	64	85.75		5	0.18	0
6	Daoliqu	43	60.60		7	0.38	0
7	Jiazhangge	96	143.30		14	0.52	1
	Majiacangbu	147	216.16		69	4.73	11
	<b>Total</b>	<b>1578</b>	<b>2864.33</b>		<b>824</b>	<b>85.19</b>	<b>77</b>

In the three years period, the results and the database of glaciers and glacial lakes generated provided the baseline data and information of the region. These results and database provide the basis for the development of monitoring and early warning system, planning and prioritization of disaster mitigation efforts that could save many lives and properties situated downstream, and a guideline for infrastructure planning and development. In addition, it is anticipated that the present study provide useful information for many of those concerned with water resources and land-use planning. Coupled with the information on climate change and future monitoring of glaciers, glacial lakes and GLOFs this database can provide the basis for estimation of future available water resources and their planning and management.

In addition methodology for inventory of glaciers and glacial lakes is developed for future glacial monitoring using GIS and RS technology. One of the major objectives of this study was to identify potential dangerous glacial lakes as source of GLOFs and downstream areas where GLOF events could pose a potential threat in the near future. Based on the detailed criteria the potentially dangerous lakes were identified which needs to be monitored in future.

The comprehensive reports and digital database generated will be of service to scientists, planners, and decision-makers in many areas. We further hope that their informed actions, will contribute to improve the lives of those living in the mountains as well as downstream and help safeguard future investments.

There are limitation on the availability and use of the topographic maps and aerial photographs. The inventory was generally based on RS and GIS and it is recommended for the field validation for the hot spot areas around the potential dangerous glacial lakes.

To covering the parts of HKH region the database of glaciers and glacial lakes using the present methodology, Nepal and Bhutan is already carried out with the support of UNEP. From present project with the support of APN and START, the area covered are sub-basins of Ganges within Tibet Autonomous Region of Peoples' Republic of China, all sub-basins of Indus River within Pakistan, and Tista River basin, Himachal Pradesh, and Utttaranchal Himalayas in India. There is still need to continue similar activity for the areas of Arunanchal Pradesh and Jammu & Kasmir Himalayas to covers the all of HKH region. Furthermore, the methods developed to capture and analysis of glaciers and glacial lakes can be used for the monitoring of glaciers and glacial lakes in future.

### Sub-basins of Indus Basin in Northern Pakistan Himalaya

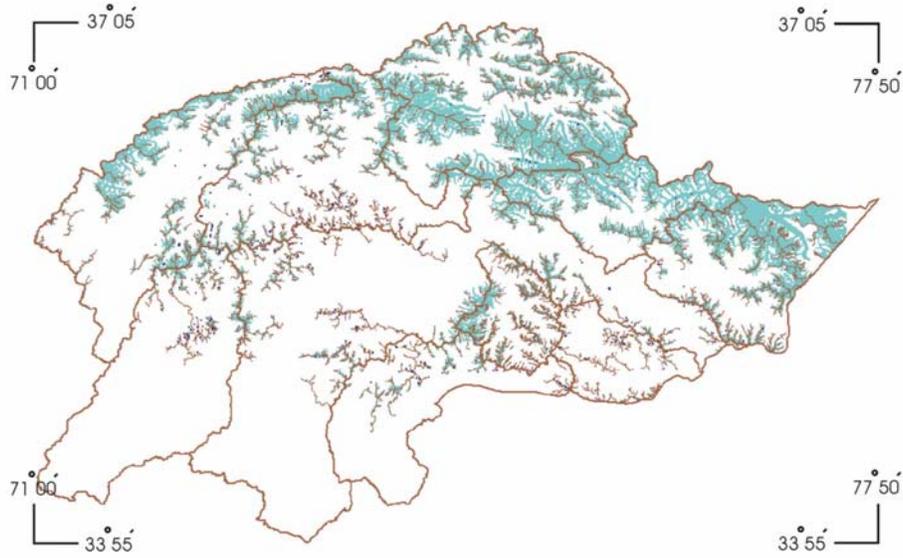


Figure: Glaciers and lakes in the sub-basins of Indus River in Pakistan

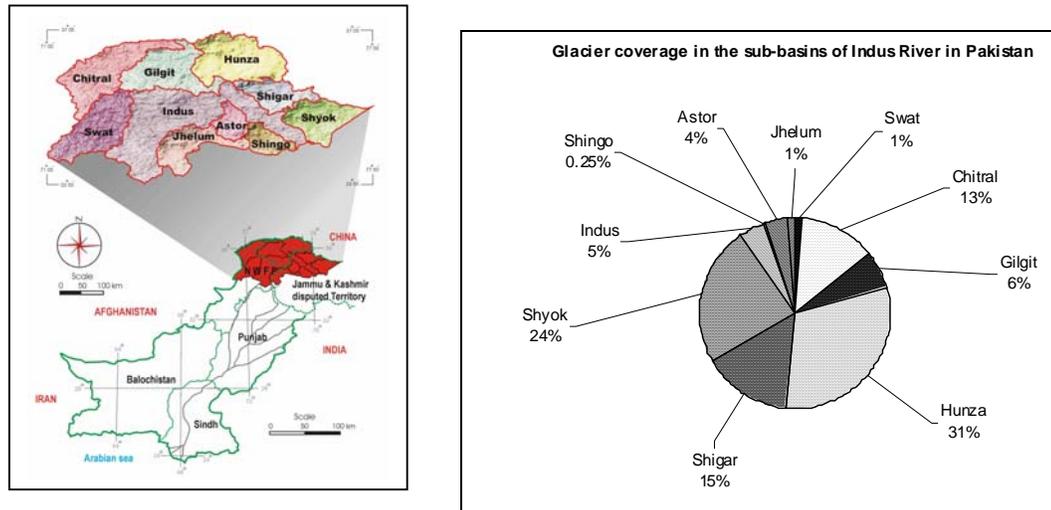


Figure: Glacier area distribution in the sub-basins of Indus River in Pakistan

### Sub-basins in Uttarakhand Himalaya

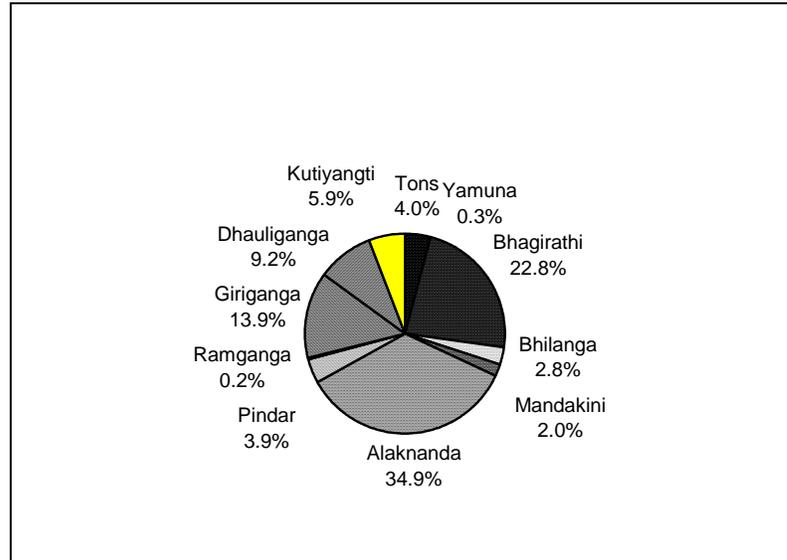


Figure: Glacier area distribution in the sub-basins of Uttarakhand Himalaya

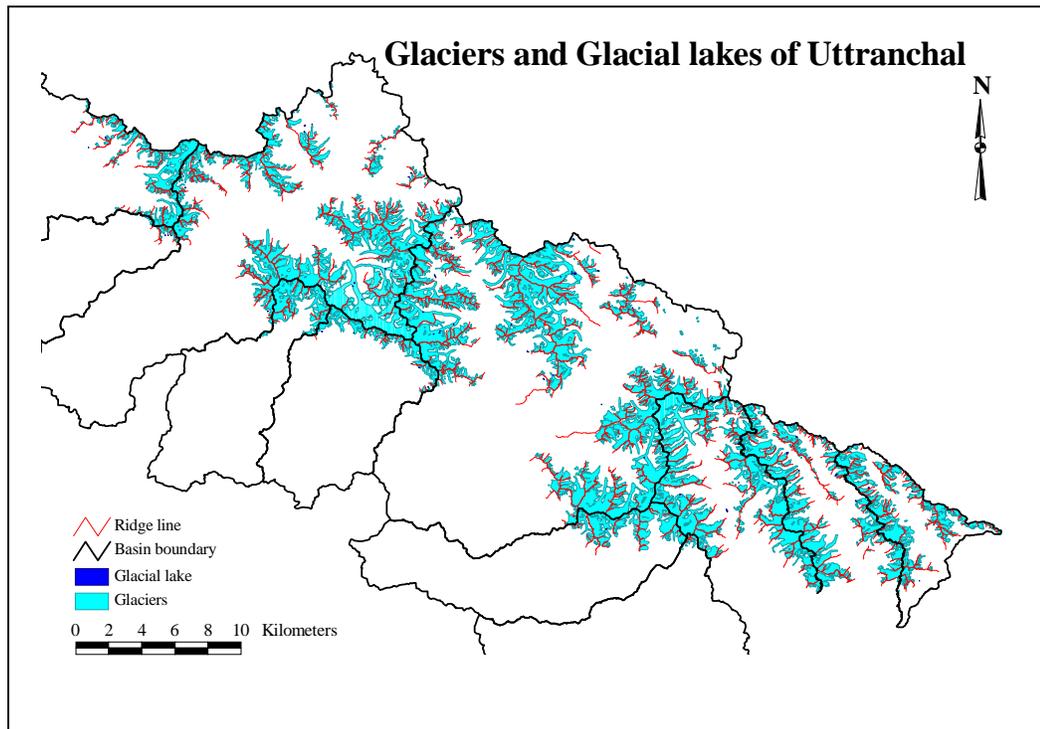


Figure: Glacier area in the sub-basins of Uttarakhand Himalaya

### Sub-basins in Himachal Himalaya

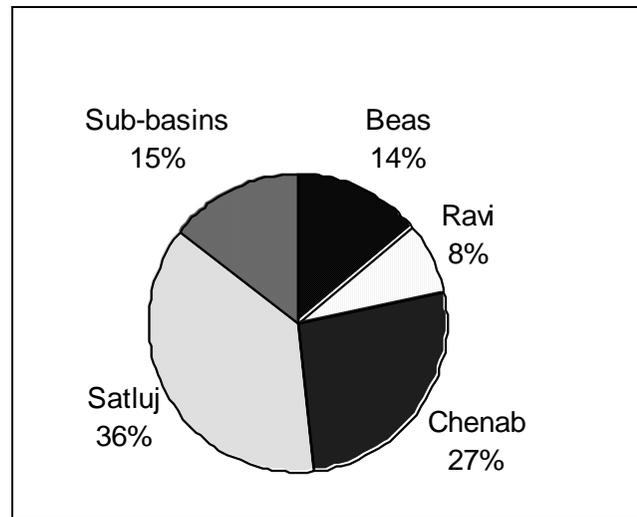


Figure: Glaciers area distribution in Himachal Pradesh.

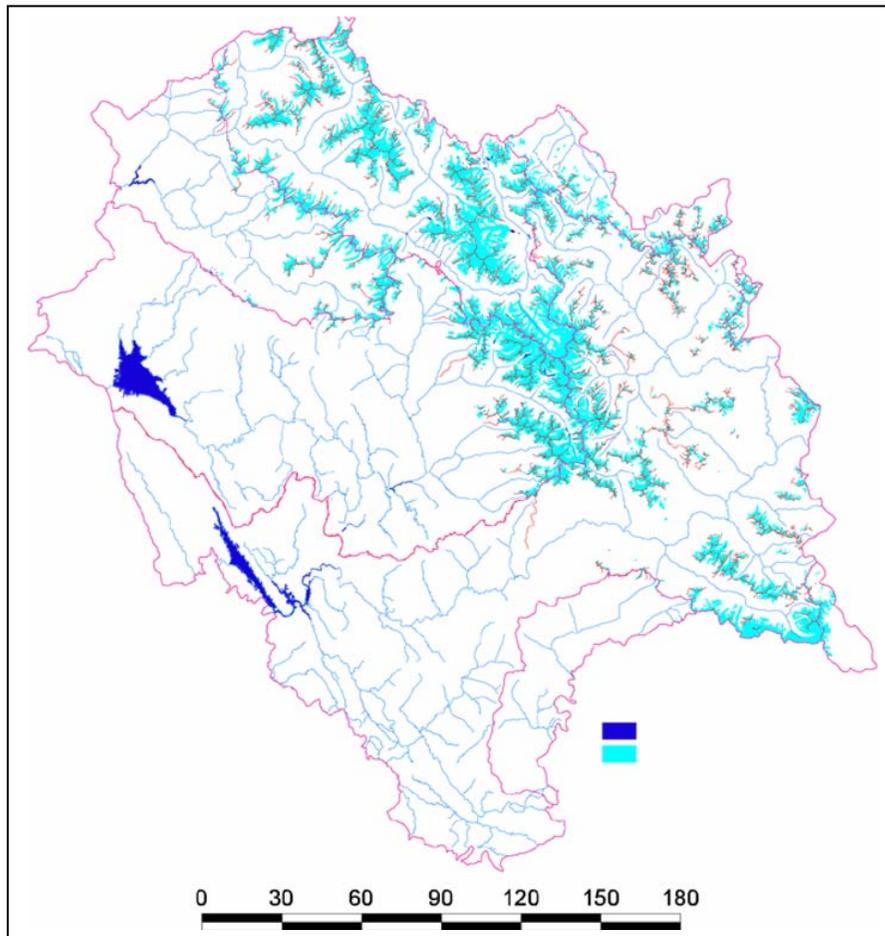


Figure: Glaciers and Glacial lakes in Himachal Pradesh.

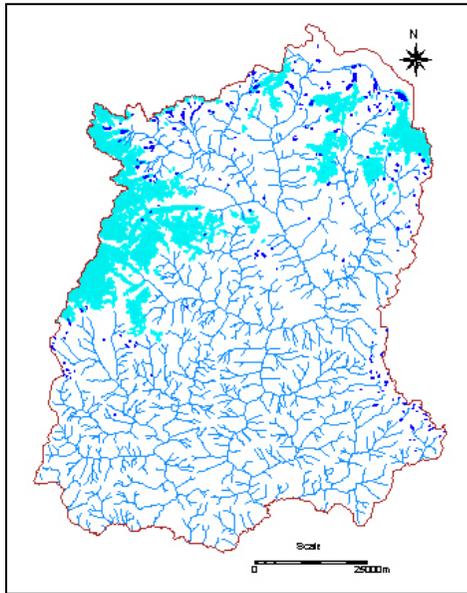


Figure: Glaciers and glacial lakes of Sikkim

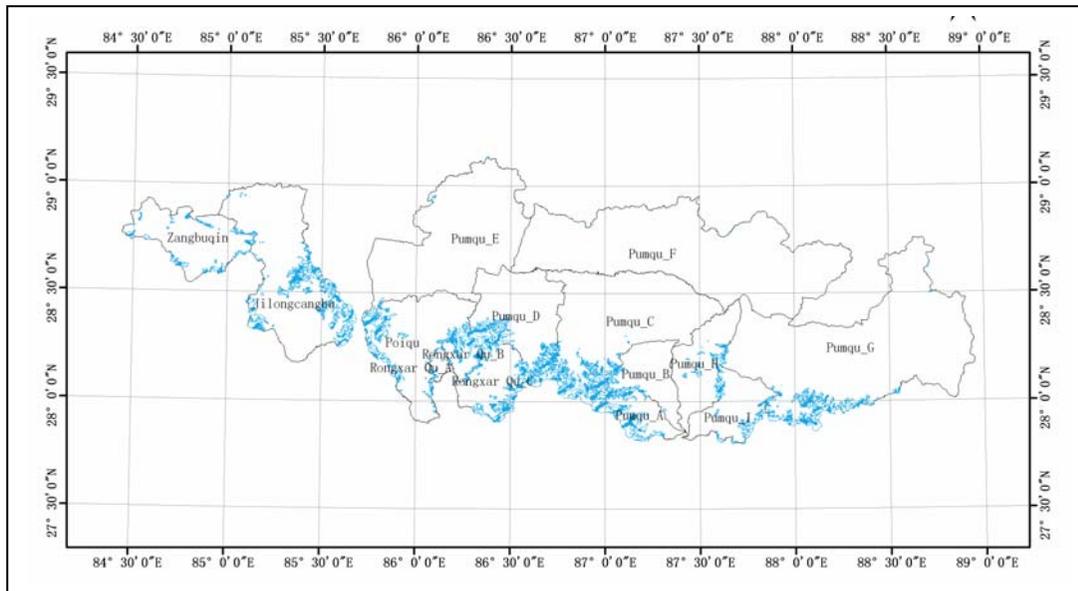
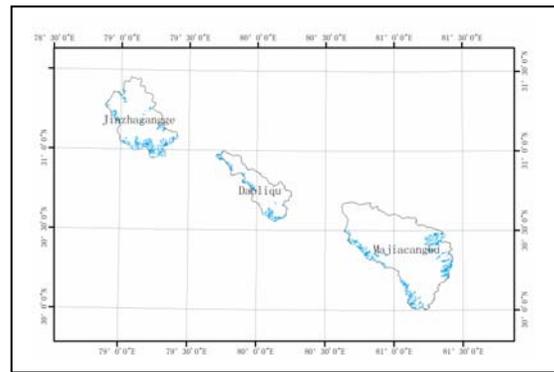


Figure: The Distribution of Glaciers in the Himalaya-China regions

## 4.0 Conclusions

The main purpose of the study was the digital repository of glaciers and glacial lakes as the major source of water supply for agricultural, industrial, and hydropower development and to assess the threat from glacial lakes and to highlight those where GLOF events are likely to occur and cause serious damage to human life and property of HKH region. These valuable resources and hazards overhead have never been systematically harnessed in the past. Knowledge of these resources and hazards seems to be an outstanding requirement for future planning of water resources and flood hazard monitoring system.

The study revealed overall 5218 glaciers with the glacier area coverage of 15040 sq km and 2420 lakes and among them 52 lakes were identified as potentially dangerous glacial lakes in Pakistan.

In India Himalaya, the Tista River basin covers only 285 glaciers with the glacier area 576 sq km, 266 glacial lakes and 14 potentially dangerous glacial lakes. The Himachal Pradesh region holds 2554 glaciers with the glacier area of 4160 sq km and 229 lakes including 22 potential GLOF. The Uttarakhand Himalayan region holds 1439 glaciers with the glacier area of 4060 sq km, though in UA 127 lakes are identified from the satellite images but not a single lake is classified in the category of potential GLOF.

Though the area of Tista River basin is comparatively very small but the number of lakes and potential GLOF is very high compared to other study region.

In Tibet Autonomous Region a total of 1578 glaciers with a glacier area of 2864 sq km were mapped in the sub-basins of Ganges River. Altogether 824 lakes were identified and among them 77 lakes are categorized in the potential GLOF.

Creating inventories and monitoring of glaciers and glacial lakes can be done quickly and correctly using a combination of satellite images supplemented by reference topographic information. The multi-stage approach of using remotely sensed data and field data will increase the accuracy of the work. The integration of visual and digital image analysis with a geographic information system (GIS) can provide very useful tools for the study of glaciers, glacial lakes, and Glacial Lake Outburst Floods (GLOFs).

The reports with information on the glaciers, glacial lakes and GLOFs of the HKH region in compatible and comparable format begin to fill this pressing need. Taken together, the database will greatly enhance the ability of global and regional climate researchers, national policy makers, land-use planners and water resource planners, as well as the general public, to understand and mitigate GLOF-associated hazards, thus linking science to policy. The project activities provided an opportunity for professionals and institutions among partners / collaborators / of the region and beyond to learn more about the methodology and related activities to build up their confidence for the future work for further cooperation.

Circulation of the reports and database in the interactive CD-ROMs and posting those also in WebPages and the workshops disseminated to wider audiences and also created much awareness.

## **5.0 Future Directions**

Except the area of Arunachal Pradesh and Jammu & Kashmir mountains of India, the digital database of glaciers and glacial lakes of the entire region of HKH has been prepared in the comparable scale. The digital repository of glaciers and glacial lakes can be used for the various applications such as water supply for agricultural, industrial, and hydropower development. In addition, special attention should be given to the reported potentially dangerous glacial lakes on the watershed while planning and implementing the new urban area, infrastructure, hydropower etc. Continued institutional capacity strengthening by advanced on-the-job training to the participants of the collaborating institutions and agencies is necessary. Analysis and synthesis of the database to locate hot-spots and potential GLOF circumstances, and dissemination of the results to the concerned agencies to conduct rapid environmental change assessment (RECA) studies on GLOF hazard risks and potential impacts in detail is required. Comprehensive communication and dissemination plan need to be developed and implemented based on the results and outputs of database analysis, to strengthen policy and planning within relevant agencies, and to inform research institutions and the public, nationally and regionally.

## References

- Ageta, Y., Kadota, T., 1992. *Predictions of Changes of Glacier Mass Balance in the Nepal Himalaya and Tibetan Plateau: A Case Study of Air Temperature Increase for Three Glaciers*. In *Annals of Glaciology*, 16: 89–94
- Ageta, Y., Ohata, T., Tanaka, Y., Ikegami, K., Higuchi, K., 1980. *Mass and Heat Balances of the Glacier AX010, Shorong Himal during the Summer Monsoon Season, East Nepal*. In Seppy, Journal of the Japanese Society of Snow and Ice, 41: 34–41 (special issue)
- Ahmed, N., Chaudhry, G.R., 1990. *Summaries of Irrigated Agriculture of Pakistan*. Lahore: Shahzad Nazir, 61-62, Gulberg-3. Lahore.
- Alford, D., 1992. *Hydrological Aspects of the Himalayan Region. Kathmandu, Nepal, ICIMOD*.
- Arnoff, S., 1989. *Geographic Information Systems: A Management Perspective*. Ottawa, Canada: WDL
- Bajracharya, S.R.; Mool, P.K.; and Joshi, S. P., 2001. *Tsho Rolpa Glacial Lake at the end of the millennium*. Proceedings of the *International symposium on geotechnical and Environmental challenges in mountainous terrain, GENSYM 2001*, Organized by Nepal Engineering College, Kathmandu, Nepal in association with Ehime University Matsuyama, Japan, Volume 1, pp.292-302.
- Bajracharya, S.R. and Joshi S., 2001. *Risk assessment of Tsho Rolpa Glacial Lake along the Rolwaling and Tama Koshi Valleys, Dolakha District*. United Nations Environmental Programme, Regional Resource Center - Asia and the Pacific (UNEP/RRC-AP) and International Centre for Integrated Mountain Development (ICIMOD), 64p.
- Balakrishnan, H., 1995. *Dammed body flow*. edited by Anil Agarwal, In *Down To Earth*, published by Sunita Narain for Society for environmental communications, New Delhi. vol. 4, No. 7: 20-21.
- Baral, D.J., Gupta, R.P., 1997. *Integration of satellite sensor data with DEM for the study of snow cover distribution and depletion pattern*, 518(18), 3889-3894
- Baral, D.J., Gupta, R.P., 1998. *Remote sensing and DEM based snow cover studies in Dokriani Bamak glacier, Garhwal Himalaya*. *Him. Geology*, Vol. 9 (1), 69-75
- Barry, R.G., 1990. *Change in mountain climate and glacio-hydrological responses*. In *Mountain Research and Development*, Published by University of California Press for United Nations University and International Mountain society. vol.10, No.2: 161-170.
- BC Hydro 1998. *Final Project Completion Report. Tsho Rolpa GLOF Warning System Project*.
- Benn, D.I., Evans, D.J.A., 1998. *Glaciers and Glaciation*. London: Arnold
- Bhusal, J.K., 1998. *Sediment Transport on Major Rivers in Nepal*. Paper presented at the International Workshop on Aspects and Impacts of Changing Sediment Regime, Asian Institute of Technology (AIT), Bangkok, Thailand. 16–20 1998,
- Bhusal, J.K., 1999. *Renewable Surface Waters of Nepal, Uses and Constraints to 21st Century*. Paper presented at the Third National Conference on Science and Technology, RONAST, Kathmandu, Nepal
- Braun, M., Fiener, P., 1995. *Report on the GLOF Hazard Mapping in the Imja Khola/Dudh Kosi Valley, Nepal*, Contribution to the Project ‘Establishment of a Measure Service for Snow and Glacier Hydrology in Nepal. Snow and Glacier Hydrology Project, Department of Hydrology and Meteorology, HMG/N
- Budhathoki, K.P., Dongol, B.K., Devkota, L.P., Dhital, N.P., Joshi, S.R., Maskey, P.R., (Damen, M.C.J., van Westen, C.J., supervisors) 1996. *Aerospace Survey and GIS for GLOF Hazard Zonation, Rolwaling and Tamakosi Valleys, Dolakha District, Nepal*, Field Work Report submitted as a Partial Requirement of the Special Postgraduate Diploma Course on ‘Mountain

- Hazard Zonation in the Himalayas, with Emphasis on GLOF' (September 5 1995–4 July 4 1996. to the ITC, The Netherlands.
- Burrough, W (Ed.) 2003. *Climate into the 21st Century*. Cambridge University press, Cambridge, U.K. pp 240.
- Carson, B.,1985. *Erosion and Sedimentation Processes in the Nepalese Himalaya*, Occasional Paper No. 1. Kathmandu: ICIMOD.
- CBS 1999. *Statistical Year Book of Nepal*.
- Census of India, 2001. *Provisional Population Totals, Distribution of workers and non-worker paper -3 of 2001*, Director of Census Operations, Sikkim, Series –12.
- Chaohai, Liu; Liangfu, Ding,1986. *The Newly Progress of Glacier Inventory in Tianshan Mountains*. In *Journal of Glaciology and Geocryology*, 8(2): 168–169.
- Chaujar, R.K., Mazari, R.K., Gergan, J.T., 1993. *Glacial geomorphology of the Gaumukh – the source of the Ganga with special reference to its present state of environment*, Proceedings of Seminar on Ganga in the Service of the Nation, University of Roorkee, 1993, 11-14.
- Chikita, K., Yamada, T., Sakai A., Ghimire, R.P., 1997. *Hydrodynamic Effects on the Basin Expansion of Tsho Rolpa Glacier Lake in the Nepal Himalaya*. In *Bulletin of Glacier Research* (Data Center for Glacier Research, Japanese Society of Snow and Ice), Publication No. 15: 59–69.
- Choudhary B.J., Chang, A.T.C., 1979. *Two stream theory of reflectance of snow*. IEEE Trans. *Geosciences and Remote Sensing* GE 17: 63-68.
- Clague, J.J. and Mathews, W.H. 1973. *The Magnitude of Jokulhlaups*. In *Journal of Glaciology*, 12(66): 501 – 504.
- Clarke, D. K. C., 1991. *Length, Width and Slope Influences on Glacier Surging*, *J. Glaciol.*, 37, 236B46.
- Clarke, D. K. C., S. G. Collins, and D. E. Thompson, 1984. *Flow, Thermal Structure, and Subglacial Conditions of a Surge-type Glacier*, *Can. J. Earth Sci.*, 21, 232B40.
- Costa, J.E., 1985. *Floods from Dam Failures*, Open File Report. USA: US Geological Survey.
- Costa, J.E., 1988. *Floods from Dam Failures*. In Baker, V.R.; Kochel, R.G.; Patton, P.C. (eds) *Flood Geomorphology*, pp 439–463. New York: Wiley Interscience.
- Coulson, A.L., *Pleistocene glaciation in north-western India, with special reference to the erratic of the Punjab*. *Rec. Geological Survey of India*, Vol. 72, 422-439.
- Damen, M., 1992. *Study on the Potential Outburst Flooding of Tsho Rolpa Glacier Lake, Rolwaling Valley, East Nepal*. The Netherlands: Netherlands–Nepal Friendship Association, International Institute for Aerospace Survey and Earth Sciences, ITC.
- Department of Hydrology and Meteorology 1998. *Hydrological Records of Nepal*, Station No. 695.
- Deonath, Nambiar, K.V., 1999. *Evidences of Palasoglaciation and Environmental Impact of Glaciogenic Deposits in the Mandakini and Madhyamaheawar Valleys*, Chamoli District, U.P. pp 59-60.
- Desloges, J.R.; Jones, D.P.; and Ricker, K.E., 1989. *Estimates of Peak Discharge from the Drainage of Ice-dammed Ape Lake, British Columbia, Canada'*. In *Journal of Glaciology*, 35: 349–354.
- DHM 1992. *Study on Nationwide Hydro-meteorological Data Management Project*, Interim Report No. 1. Department of Hydrology and Meteorology/Japan International Cooperation Agency (JICA).
- DHM 1997a. *Snow and Glacier Hydrology Section Year Book 1995*, Supplement No. V. Nepal: Snow and Glacier Hydrology Section, Department of Hydrology and Meteorology, HMG/N.
- DHM 1997b. *Thulagi Glacier Lake Study*, final report. Department of Hydrology and Meteorology, HMG/N in cooperation with Federal Institute for Geo-sciences and Natural Resources (BGR), Hannover, Germany.
- DHM 1997c. *Tsho Rolpa GLOF Risk Reduction Project*, Formulation Mission Final Report.

- DHM 1998a. *Hydrological Records of Nepal. Streamflow Summary*. Nepal: DHM, HMG/N.
- DHM 1998b. *Tsho Rolpa GLOF Risk Reduction Project, Implementation Report*
- DHM 1999a. *Climatological Records of Nepal. 1995–1996*. Nepal: DHM, HMG/N
- DHM 1999b. *Daily Precipitation Record of Gandaki and Narayani Zone through 1996*. Nepal: DHM, HMG/N.
- DHM 2000. *Tsho Rolpa GLOF Risk Reduction Project, Design Build and Project Management Contracts, Quarterly Progress Report No. 5*
- Dobhal, D.P., Kumar, S., Mudepi, A.K., 1991. *Mass wasting and slope analysis of Chhota Shigri Glacier (HP)*. Jour. *Him. Geol.* Vol 2 (2), 119-124.
- Dobhal, D.P., Kumar, S., Mudepi, A.K., 1995. *Morphology and glacier dynamics studies in monsoon – arid transit zone: as example from Chhota Shigri Glacier Himachal -Himalaya*. *Current science*, Vol 64 (9), 936-944.
- Dobhal, D.P., Kumar, S., 1996. *Inventory of glacier basins in Himachal Himalaya*. Jour. *Geol. Soc., India*. Vol 48, 671- 681.
- Dobhal, D.P., Kumar, S., 1997. *Statistical analysis of glaciers in Himachal Pradesh north-west Himalaya, India*. *Current Sci.* Vol 72 (5), 341-344.
- Dobhal, D.P., Gergan, J.T., Thayyen, R.J. 1999. *Recession of Dokriani Glacier, Garhwal Himalaya - An overview*. *Symp. On snow, ice and glaciers. A Himalayan Perspective. Geol. Survey India*, (In: Abst. Vol.), 30-33.
- Dobhal, D.P., Gergan, J.T., Thayyen, R.J., 2004. *Recession and Morphogeometrical Changes of Dokriani Glacier (1962-1995) Garhwal Himalaya, India*. *Current Science*, 86, (3)101-107.
- Dozier, J., 1984. *Snow reflectance from Landsat-4 Thematic Mapper*, *IEEE Trans. Geosciences and Remote Sensing*, GE-22 (3), 323-328.
- Dozier, J., Schneider, S.R., Mc Ginnis, D.F. Jr., 1981. *Effect of grain size and snow pack water equivalence on visible and near infra red satellite observations of snow*. *Water resource. Res.*, 17, 1213-1221.
- Dwivedi, S.K., Acharya, M.D., Joshi, S. P. 1999. 'Preliminary Report on the Tam Pokhari GLOF of 3rd September 1998'. In *WECS Bulletin*, 10(1): 11–13
- Electricity Development Center 1994. *Detailed Project Report (DPR) Pancheshwar Multipurpose Project*.
- Electrowatt Engineering Service Ltd. 1982. *Feasibility Study of Mulghat Hydropower Project*, Report to Asian Development Bank and HMG/N
- ESCAP 1993. *Geology and Mineral Resources of Nepal*. In *Atlas of Mineral Resources of the ESCAP Region*, Vol 9. Economic and Social Commission for Asia and the Pacific in cooperation with the Department of Mines and Geology, Ministry of Industry, HMG/N.
- Farrukh, M.. 2002. *Saviours of Karakoram Highway at Work*, The Crops of Engineers Journal, *Military college of Engineering*, Risalpur.
- Francis M. R., K. J. Miller and Dong Zhi-bin, 1984. *Impulse Radar Ice-depth Sounding of the Gulkin Glacier*, In K. J. Miller, *The International Karakoram Project-2*. Cambridge University Press, p-111.
- Galey, V.J., 1985. *Glacier Lake Outburst Flood on the Bhote/Dudh Kosi, August 4, 1985*, WECS internal report. Kathmandu: WECS
- Gansser, A., (1964) *Geology of the Himalayas* Interscience publishers, a division of John Wiley & Sons Ltd. 289pp.
- Gautam, C.K., Mukherjee, B.P., 1989. *Mass balance vis-à-vis snout position of Tipra Bank glacier, District Chamoli, U.P.* Proc. *National meet on Himalayan Glaciology*, 141-148.
- Galey, V.J., 1985. *Glacier Lake Outburst Flood on the Bhote/Dudh Kosi, August 4, 1985*, WECS internal report. Kathmandu: WECS.

- Gazdar, M.N., 1987. *Groundwater and the Environment: Pakistan Scenario*. In *Groundwater and the Environment: Proceedings of the International Groundwater Conference 1987*. Malaysia: University Kebangsaan. H12-21.
- Geological Survey of India, 1999. *Inventory of the Himalayan glaciers*, a contribution to the international Hydrological Programme, special publication no 34, pp165.
- Gergan, J.T., Dobbal, D.P., 1997. *Results of Expedition to Dokriani Bamak, Garhwal Himalaya, India*. National Symposium on Himalayan Glaciers and Snow Cover- 3-4 March 97.
- Gergan, J.T., Dobhal, D.P., Kaushik, R., 1999. *Ground penetrating radar ice thickness measurements of Dokriani Bamak (glacier), Garhwal Himalaya*, *Current Science*, Vol. 77 (1), 169-173.
- Gergan, J.T., Dobhal, D.P., Thayyen, R. J. 1999. *Determination of ice thickness of Dokriani Glacier, Garhwal Himalaya, U.P., using GPR Technique*. Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Abstracts 132-133
- Gilbert, L.B., Auden, J.B., 1933. *Note on a Glacier In the Arwa valley, British Garhwal*. Rec, *Geological Survey of India*, Vol. 66(3), pp. 214-278.
- Glacier Atlas of the Tista basin*, 2001.
- Government of India (GOI) 1981. *Feasibility Report of Kosi High Dam Project*. 3-23.
- GOP, 1998. *Agriculture Statistics of Pakistan*. Economic Wing of the Ministry of Food, Agriculture and Livestock, Government of Pakistan.
- GOP, 2001. *Population Census Organization 1998*, Pakistan Statistical yearbook 2001, Federal Bureau of Statistics, Statistics division, Islamabad, Pakistan.
- GOP, IUCN, *World Conservation Union*, IIED and UNDP 1992. Pakistan National Report to UNCED. Environment and Urban Affairs Division, Government of Pakistan.
- GOP, 1992. *Agriculture Statistics of Pakistan*. Economic Wing of the Ministry of Food, Agriculture and Livestock, Government of Pakistan.
- Goudie, A.S., D. Brunnsden, D.N. Collin, E. Derbyshire, R.I. Ferguson, Z. Hashmet, D.K.C. Jones, F.A. Perrott, M. Said, R.S. Waters and W.B. Whalley. 1984. *The Geomorphology of Hunza Valley, Karakoram Mountains, Pakistan*. In Keith Miller, Proceedings of the International Karakoram Project. London: *Royal Geographical Society*. pp. 359-410.
- Grabs, W.E., Pokhrel, A.P., 1992. *Establishment of Measuring Service for Snow and Glacier Hydrology in Nepal—Conceptual and Operational Aspects*. In Young, G.J. (ed.) *International Symposium on Snow and Glacier Hydrology*, pp 3–16. Kathmandu: IAHS.
- Gunn, J.P., 1930. *Report of the Khumdan Dam and Shyok Flood of 1929*. Government of Punjab Publication: Lahore, Pakistan.
- Hall, D.K., Chang, A.T.C. Siddalingaiah, 1988. *Reflectance of glaciers as calculated using Landsat-5 Thematic Mapper data*. *Remote Sensing Environment*, 25, 311-321.
- Hammond, J.E., 1988. *Glacial Lake in the Khumbu Region, Nepal: An Assessment of the Hazards*. MA Thesis. Boulder, USA: Department of Geology, University of Colorado.
- Hanisch, J., Delisle, G., Pokhrel, A.P., Dixit, A.M., Reynolds, J.M., Grabs, W.E. 1998. *The Thulagi Glacier Lake, Manasulu Himal, Nepal—Hazard Assessment of a Potential Outburst*. In Moore, D., Hungr, O. (eds) *Proceedings of Eighth International Congress International Association for Engineering Geology and the Environment, 21–25 September 1998, Vancouver, Canada*, pp 2209–2215.
- Hansen, J., Ruedy, R., Sato, R., Reynolds, R., 1996. *Global Surface Air Temperature in 1995: Return to Pre-Pinatubo Level*. *Geophysical Research Letters*, 23: 1665–1668.
- Harza Engineering Co. International., 1975. *Appraisal of Flood Management Systems in Pakistan*. Lahore.
- Hasnain, S.I., Thayyen, R.J., 1994. *Hydrograph separations of bulk melt waters of Dokriani Bamak glacier basin, based on electrical conductivity* *Current Science*, Vol. 67(3).
- Hasnain, S.I., Thayyen, R.J., 1996. *Sediment transport and Solute variation in melt water of*

- Dokriani Glacier (Bamak), Garhwal Himalaya. Journal Geological Society of India, Vol. 47, 731-739.*
- Hasnain, S.I., Thayyen, R.J., 1996. *Variation of Discharge and Solute concentration in the Melt waters of Dokriani (Bamak) Glacier, Garhwal Himalaya, India. Journal Geological Society of India, Vol. 47, 89-93.*
- Hasnain, S.I., Thayyen, R.J., 1997. *Dissolved Load in Dokriani Glacier Melt waters National Symposium on Himalayan Glaciers and Snow Cover- 3-4 March 97 Abstracts, JNU, New Delhi.*
- Hasnain, S.I., 1999. *Runoff and Sediment Concentration of Melt waters Draining from Himalayan Glaciers Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99 Abstracts, Geological Survey of India, pp 46-47.*
- Hasnain, S.I., Thayyen, R.J., 1999. *Controls on the major-Ion chemistry of the Dokriani glacier meltwaters, Ganga basin, Garhwal Himalaya, India. Journal of Glaciology Vol. 45, (149) 87-92.*
- Hasnain, S.I., Thayyen, R.J., 1999. *Discharge and suspended-sediment concentration of melt waters, draining from the Dokriani glacier, Garhwal Himalaya, India. Journal of Hydrology, Vol. 218, 191-198.*
- Hewitt, K., 1969. *Glacier Surges in the Karakoram Himalaya (Central Asia). Canadian Journal of Earth Science 6:1009-1018.*
- Hewitt, K. 1985. *Pakistan Case Study: Catastrophic Floods*, Publication No. 149. UK: IAHS.
- Hewitt, K., 1989. *The Altitudinal Organization of Karakoram Geomorphic Processes and Depositional Environments. Zeitschrift Geomorph., 76: 9-32.*
- Hewitt, K., 1998. *Recent Glacier Surges in the Karakoram Himalaya, South Central Asia, [http://www.agu.org/eos\\_elec/97016e.html](http://www.agu.org/eos_elec/97016e.html), © 1998 American Geophysical Union.*
- Hewitt, K., 1990. *Overall Report: Snow and Ice Hydrology Project, Upper Indus Basin SIHP, Cold Regions Research Centre, Wilfrid Laurier University, 179 pp.*
- Hewitt, K., 1993. *Altitudinal Organisation of Karakoram Geomorphic Processes and Depositional Environments, Chapter 7, In Shroder J. F., Jr., Routledge, Himalaya to the Sea: Geology, Geomorphology and the Quaternary, London, 159B83,.*
- Higuchi, K., Fushimi, H., Ohatga, T., Iwata, S., Yokoyama, K., Higuchi, H., Nagoshi, A., Iozawa, T., 1978. *Preliminary Report on Glacier Inventory in the Dudh Kosi Region. Seppyo, Journal of the Japanese Society of Snow and Ice, 40: 71-77 (special issue).*
- Himal Power Consultants and Karnali (Chisapani) Multipurpose Project 1989. *Feasibility Study (Main Report) Submitted to Ministry of Water Resources, HMG Nepal, 11-1 to 11-7.*
- Himalayan Power Consultants 1989. *Karnali (Chisapani) Multipurpose Project, Annex E, Sedimentation, 1-2.*  
<http://sikkim.nic.in/sws/statistical-map.html>  
[http://sikkim.nic.in/sws/gis\\_pop\\_table.html](http://sikkim.nic.in/sws/gis_pop_table.html)  
<http://www.imd.ernet.in/section/climate/monsoon.onset.htm>
- Hughes R. E. 1984. *Yasin Valley: The Analysis of Geomorphology and Building Types*, In Miller, K. J. *The International Karakoram Project-2 Cambridge University Press*, pp-272, 273.
- Ives, J.D., 1986. *Glacial Lake Outburst Floods and Risk Engineering in the Himalaya*, Occasional Paper No. 5. Kathmandu: ICIMOD.
- Iwata, S., 1976. *Late Pleistocene and Holocene Moraines in the Sagarmatha( Everest) Region, Khumbu Himal. In Seppyo, Journal of the Japanese Society of Snow and Ice, 38: 109-114 (special issue).*
- Jangpangi, B.S., Vohra, C.P., 1962. *The retreat of the Skunkulpa (Ralam) glacier in Central Himalaya, Pithoagarh District U.P. Inst. Assoc. Scienc. Hydrology Pub., 58, 234-238.*
- Jain, A.; 2000. *Study of sacred Khecheopalri Lake ecosystem in the Sikkim Himalaya*, University of

- North Bengal, Raja Rammohanpur, West Bengal-734430, India, Ph. D. thesis, 232pp.
- Jain, A.; Rai, S.C.; Pal, J.; and Sharma, E. 1999. *Hydrology and Nutrient Dynamics of a Sacred Lake in Sikkim Himalaya*. In *Hydrobiologia* 416: 13-22.
- Jain, A.; Rai, S. C.; and Sharma, E. 2000. *Hydro-ecological Analysis of a Sacred Lake Watershed System in Relation to Land-use/Cover Change from Sikkim Himalaya*. In *Catena* 40 (2000): 263-278.
- JICA 1983. *Feasibility Report on Sapta Gandaki Hydroelectric Power Development Project*. Submitted to HMG Nepal Vol. 1 (4 –13) and Vol II (c-19 to c-22).
- JICA 1985. *Master Plan Study on the Kosi River Water Resources Development*. Submitted to HMG Nepal, Vol. I and Vol. II.
- JICA 1987. *Draft Final Report on Feasibility Study on Arun 3 – Hydro-Electric Power Development Project Vol. I Main Report*, 5 – 43.
- Johnson, P.G., 1988. *Glacier-dammed lakes and mass movement-dammed lakes, Upper Hunza valley, Pakistan*. Unpubl. Paper, Snow and Ice Hydrology Project, Wilfrid Laurier University.
- Jones, P.D., New, M., Parker, D.E., Martin, S., Rigos, I.G., 1999. *Surface air temperature and its changes over the last 150 years*. Review of Geophysics and Space physics, 37, 173-199.
- Joshi, S.C., Joshi, D.R., Dani, D.D., 1993. *Kumaun Himalaya: A geographic perspective on resource development*. Publisher, Gyanodaya Prakashan, Naini Tal, pp.324.
- Joshi, S.C., Joshi, D.R., Dani, D. D., 1997. *Uttarakhand Paryavaran Manchitrawali*, Uttarakhand Paryavaran Shakshia Kendra, Almora, pp 197.
- Kadota, T., Ageta, Y. 1992. *On the Relation between Climate and Retreat of Glacier AX010 in the Nepal Himalaya from 1978 to 1989*. In *Bulletin of Glacier Research*, 10: 1–10.
- Kamb, W. B., 1987. *Glacier Surge Mechanism Based on Linked Cavity Configuration of the Basal Water Conduit System*, *J. Geophys. Res.*, 92(B9), 9,083B9, 100.
- Kamp, U., 1999. *Late Quaternary Geomorphology and Glaciation in the Eastern Hindu Kush, Chitral, Northern Pakistan / Jungquartäre Geomorphologie und Vergletscherung im östlichen Hindukusch, Chitral, Nordpakistan*. *Berliner Geographische Studien*, 50, Berlin, 254 pp. (In German). (ISBN: 3-7983-1812-3).
- Kaul, M.K., Puri, V.M.K., Singh, R.K., Srivastava, D., Sangewar, C.V., Swaroop, S. and Gautam, C.K., 1999. *Inventory of the Himalayan Glaciers*, GSI Sp. Pub. 34, 1-165.
- Kaushic, S. D., 1962. *Climatic zones and their related socio-economy in Garhwal Himalaya*. *Geog. Review*, 24(3-4), 29.
- Kazmi, A. H., Qasim, M. 1997. *Geology and Tectonics of Pakistan*. Graphic Publishers, Karachi, Pakistan.
- Kettelmann, R., Watanabe, T., 1998. *Approaches to Reducing the Hazard of an Outburst Flood of Imja Glacier Lake, Khumbu Himal*. In Chalise, S.R., Khanal, N.R. (eds) *Proceeding of the International Conference on Ecohydrology of High Mountain Areas, Kathmandu, Nepal, 24-28 March 1996*, pp 359–366. Kathmandu: ICIMOD
- Kelly, R.E.J., 1988. *Preliminary investigations into the formation and drainage of the glacially-dammed Virjerab lake, Shimshal valley, Northern areas, Pakistan*. Unpubl. Paper, Snow and Ice Hydrology Project, Wilfrid Laurier University.
- Khan, M. I., 1994. *Glaciology- Glacier and Avalanche Research*. Peshawar.
- Kick, W., 1964. *The Chogo-Lungma Glacier, Karakoram*. *Zeitschrift Gletscherkunde und Glazialgeologie*, 5(1): 59p.
- Kodama, H., Mae, S. 1976. *The Flow of Glaciers in the Khumbu Region*. Seppyo, *Journal of the Japanese Society of Snow and Ice*, 38: 31–36 (special issue).
- Kraus, H., 1988. *The Climate of Nepal, Studies on the Climatology and Phytogeology of the Himalaya: Selections from Khumbu Himal*. Kathmandu: Nepal Research Centre

- Kulkarni, A. V. and Narain, A., 1990. *Remote sensing based glacier inventory in the Sikkim State* scientific note, Marine and Water Resources Division, Remote Sensing Applications Group Space Applications Centre, Ahmedabad 380053. SAC/RSA/RSAG-MWRD/SN/01/90.
- Kulkarni, A.V., 1991. *Glacier inventory in Himachal Pradesh using satellite images. Photonirvachak*, 19, 195-203.
- Kulkarni, A.V., Buch, A.M., 1993. *Remote Sensing based glacier inventory in Indian Himalaya*. Int. Sem. On hydrology with a special colloquium on environmental problems and water resources of Himalayan region Katmandu, Nepal, 10 pages
- Kulkarni, A.V., 1994. *A conceptual model to assess effect of climatic variations on distribution of Himalayan glaciers. Scientific Report (Unpublished)-ISRO-IGBP SR 42-94, 321-326.*
- Kulkarni, A.V., Philip, G., Thakur, V.C., Sood, R.K., Randhawa, S.S., Ram C., 1999. *Glacial inventory of the Satluj Basin using remote sensing technique. Journal of Himalayan Geology*, 20(2), 45-52.
- Kumar, S., Dobhal, D.P., 1994. *Snout fluctuation study of Chhota-Shigri glacier, Lahul and Spiti District, Himachal Pradesh. Jour. Geol. Soc. India*, 4, 581-585.
- Lahiri, A. K; Chattopadhyay, S; Bhasin, A; Premchand, A; and Roy,S. 2001. *Sikkim, the peoples's vision*. ISBN 81-7387-123-X, Indus Publishing Company, New Delhi and Government of Sikkim, Gangtok. 139pp.
- Liboutry, L.; Arnoa, B.M.; and Schnieder, B. 1977a. *Glaciological Problems set by the Control of Dangerous Lake in Cordillera Blanca, Peru; Part I; Historical Failures of Morainic Dams, their Causes and Prevention*. In *Journal of Glaciology*, 18(79): 000–000.
- Liboutry, L.; Arnoa, B.M.; Schnieder, B. 1977b. *Glaciological Problems set by the Control of Dangerous Lake in Cordillera Blanca, Peru; Part II; Movement of a Covered Glacier Embedded within a Rock Glacier*. In *Journal of Glaciology*, 18(79): 000–000.
- Liboutry, L.; Arnoa, B.M.; Schnieder, B. 1977c. *Glaciological Problems set by the Control of Dangerous Lake in Cordillera Blanca, Peru; Part III; Studies of Moraines and Mass Balances at Safund*. In *Journal of Glaciology*, 18(79): 000–000
- LIGG/WECS/NEA, 1988. *Report on First Expedition to Glaciers and Glacier Lakes in the Pumqu (Arun) and Poique (Bhote-Sun Kosi) river basins, Xizang (Tibet), China, Sino-Nepalese Investigation of Glacier Lake Outburst Floods in the Himalaya*. Beijing, China: Science Press.
- Malaviya, A.K., Pande, A.C., Bajpai J.P., Misra R.S., 1999. *Imprints of Quaternary Glaciation in Upper Kali Valley, District Pithoragarh, U.P. Abstracts, Geological Survey of India*, pp 65-66 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99.
- Mae, S., 1976. 'Ice Temperature of Khumbu Glacier'. In *Seppyo, Journal of the Japanese Society of Snow and Ice*, 38: 37–38 (special issue).
- Marcus, M.G., 1960. 'Periodic Drainage of Glacier-dammed Tulsequah Lake, B.C.'. In *Geographical Review*, 31: 000–000.
- Mason, K., 1930. *The Glaciers of the Karakoram and Neighborhood. Geological Survey. India, Rec*, 63: 214-278.
- Mason, K., 1935. *The Study of Threatening Glaciers. Geog. J.*, 85: 24-41.
- Mastny, L., 1999. *Melting of earth's ice cover reaches new high*. Website:<http://www.worldwatch.org/alerts/000306.htm>
- Mayeswki, P.A., Jeschke, P.A., 1979. *Himalayan and Trans-Himalayan glacier fluctuation since AD 1812. Arctic and Alpine Research*, 11(3), 267-287.
- Mayewski, P., G. P. Pergeant, P. A. Jeschke, and N. Ahemad, 1980. *Himalayan and Transhimalayan Glacier Fluctuations and the S-Asian Monsoon Record*, *Arctic and Alpine Research*, 12/1, 171B82.
- Mercer J. H., 1975. *Mountain Glaciers of the Northern Hemisphere, U. S. Cold Regions Res. and Engg. Lab., In W. O. Field (ed.), Hanover, N. Y.*, 1: 371-409.

- Miller, K.J., 1984. *The International Karakoram Project: Proceedings of Conferences in Islamabad and London*. 2 vols. Cambridge: Cambridge University Press.
- Ministry of Agriculture, 1997. *Atlas of Bhutan, 1:250,000, Land Cover and Area Statistics of 20 Dzongkhags; Land Use Planning Project, Bhutan*. Thimpu, Bhutan: Land Use Planning Section, Policy and Planning Division in the Ministry of Agriculture.
- Modder S., van Olden, Q., 1995. *Geotechnical Hazard Analysis of a Natural Moraine Dam in Nepal*, Interim Report. The Netherlands: Free University of Amsterdam.
- Modder S., van Olden, Q., 1996. *Engineering—Geomorphological Analysis of Moraine Dam in the Nepal Himalayas, A detail survey (scale 1:1500) at Tsho Rolpa Glacier Lake, Rolwaling Valley, Dholakha District, East Nepal*, Part 1: text. MSc Thesis. The Netherlands: Faculty of Earth Sciences, Vrije Universiteit Amsterdam.
- Modder S., van Olden, Q., 1996. *Engineering—Geomorphological Analysis of Moraine Dam in the Nepal Himalayas, A detail survey (scale 1:1500) at Tsho Rolpa Glacier Lake, Rolwaling Valley, Dholakha District, East Nepal*, Part 2: appendices. MSc Thesis. The Netherlands: Faculty of Earth Sciences, Vrije Universiteit Amsterdam.
- Modder S., van Olden, Q., 1996. *Preliminary Presentation of Geotechnical Data and Maps (separate) of The Tsho Rolpa End Moraine Complex*. The Netherlands: Vrije Universiteit Amsterdam.
- Mool, P.K., 1995a. 'Glacier Lake Outburst Floods in Nepal'. In *Journal of Nepal Geological Society*, vol 11: pp273–280 (special issue).
- Mool, P.K., 1995b. *Monitoring of Land Cover of Glaciated Mountain Environment, Rolwaling—Sagarmatha (Everest) Area, Nepal, using Remote sensing (ERDAS IMAGINE) and GIS Technique*, report on JICA Counter Part Training. Tokyo, Japan: PASCO Corporation.
- Mool, P.K., 1998. *Use of Multi-Temporal Data for the Study of Glacier Lakes and Glacier Lake Outburst Floods in Nepal Himalaya: Tsho Rolpa Glacier Lake as a Case Study*. In *Proceedings of International Symposium on Application of Remote sensing and Geographic Information System to Disaster Reduction, Tsukuba, Japan, 3 March 1998*, pp 13–21.
- Mool, P.K.; Bajracharya, S.R.; and Joshi, S. P., 2001: *Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning system in the Hindu Kush-Himalayan Region, Nepal*. 364P. ICIMOD, ISBN 92 9115 331 1, 365pp.
- Mool, P.K.; Wangda, D.; Bajracharya, S.R.; Joshi, S. P., Kunzang, K.; and Gurung, D.R., 2001: *Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning system in the HinduKush-Himalayan Region, Bhutan*. ICIMOD, ISBN 92 9115 345 1, 227pp.
- MOPE 1998. *State of the Environment, Nepal*. Nepal: Ministry of Population and Environment, HMG/N.
- Morton 1983. *Operational Estimates of Aerial evapo-transpiration and their Significance to the Science and Practice of Hydrology*. In *Journal of Hydrology*, 66: 1–76.
- Muller, F., 1959. *Eight Months of Glaciers and Soil Research in the Everest Region (The Mountain World 1958/59)*, pp 191–208. London: Allen & Unwin.
- Muller, F.; Caflish, T.; Muller, G, 1977. *Instruction for Compilation and Assemblage of Data for a World Glacier Inventory*. Zurich: Temporary Technical Secretariat for World Glacier Inventory, Swiss Federal Institute of Technology, Zurich.
- Muller, F., 1980. *Present and Late Pleistocene Equilibrium Line Altitudes in the Mt. Everest Region—An Application of the Glacier Inventory*, Riederalp Workshop. IHAS-AISH.
- NACS, 2001. *Support Project, Northern Areas Strategy for Sustainable Development Background Paper on "Water"* Final Draft.
- Naithani, A.K., Nainwal, H.C., Sati, K.K., Prasad, C., 2001. *Geomorphological evidences of retreat of the Gangotri glacier and its characteristics*. *Current Science*, 80 (1), 87-94.

- Naithani, A.K., Prasad, C., Nainwal, H.C., 1999. *Glacio-Fluvial Geomorphological investigation of the Mandakini Valley Between Chaurabari Glacier and Rambara of Garhwal Himalaya, India* Abstracts, *Geological Survey of India*, pp 101 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99.
- Nakawo, M., Fujita, K., Ageta, Y., Shankar, K., Pokhrel, A.P., Yao, T., 1997. *Basic Studies for Assessing the Impacts of the Global Warming on the Himalayan Cryosphere, 1994–1996*. *Bulletin of Glacier Research*, 15: 53–58
- Nawani, P.C., Gupta, U.P., Khanduri, H.C., 2002. *Significance of Geotechnical Investigation for Development of Hydropower Projects in Uttaranchal State*. In N.K. Verma (Ed.) *Proceeding national Workshop on “Natural Wealth of Uttaranchal”* Pp. 1-91-100
- Nayava, J.L., 1980. *Rainfall in Nepal*. In *The Himalayan Review*, 12: 1–18
- NEA 1995. *Report on the Field Trip to the Lower Barun Glacier Lake on 17/4/1995*. Arun III Hydroelectric Project, Detailed Engineering Services, Joint Venture Arun III Consulting Services, Lahmeyer International, Energy Engineering International, and Electric Power Development Company Ltd
- Neda 2000. *Tsho Rolpa GLOF Mitigation Projects. Analysis of Micro-tunneling Option*
- NESPAK and Harza Engineering Co. International, 1979. *National Flood Protection Plan-1978*. Islamabad, Pakistan.
- NESPAK, 1987. *National Flood Protection Plan-Phase II*. Lahore, Pakistan.
- NESPAK, 1989. *1988-Flood Damages Restoration Project*. Lahore, Pakistan
- Nijampurkar, V.N., Rao, D.K, Sarin, M.M., 1999. *Ice Dynamics Studies on Dokriani Bamak Glacier, Central Himalaya, Based on Radioactive and Stable Isotopes* Abstracts, *Geological Survey of India*, pp 162-163 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Nippon Koei Co. Ltd. Tokyo 1966. *Hydroelectric Development of the Karnali River, Nepal* Feasibility Report on the Chisapani High Dam Project, Report prepared for the United Nations Action as Executive Agency for the UNDP, Vol. II, 31-38.
- Nityanand, Kumar, K., 1986. *The Holi Himalaya*. Publisher, Daya Publishing House, Delhi
- NPC 1998. *Ninth Five Year Plan (1996/97–2001/02)*
- Nurkadilov, L.K.; Khagai, A.U.; Popov, N.V., 1986. *Artificial Draining of an Outburst-dangerous Lake at the Foot of Surging Glacier*. In *Data of Glaciological Studies*, 18: 220–221
- Oberoi, L.K., Srivastava, D., Shulda, S.P., Bhattacharya, U., 1999. *Analysis and Interpretation of Glacier Inventory Data of Alaknanda Basin, U.P. Himalayas* Abstracts, *Geological Survey of India*, 91-92 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- O'Brien, H.W., Munis, R.H., 1975. *Red and near infrared spectral reflectance of snow*. In: *Operational Applications of satellite snow cover observations*. Proceedings of a workshop, NASA SP-391, 345-360
- Orheim, O., Lucchitta, B.K., 1987. *Snow and ice studies by Thematic Mapper and multispectral scanner Landsat images*. *Annals of Glaciology*, 9, 109-118
- Ostrem, G., 1975. *ERTS data in glaciology, an effort to monitor glacier mass balance from satellite imagery*. *Journal of Glaciology*, 15, 403-415
- Owen, L. 1988a. *Terraces, Uplift and Climate, the Karakoram Mountains, Northern Pakistan*. Unpublished Ph.D. thesis, Department of Geography, University of Leicester, UK.
- Owen, L.A. 1989. *Terraces, Uplift and Climate in the Karakoram Mountains, Northern Pakistan: Karakorum Intermontane Basin Evolution*. - *Zeitschrift für Geomorphologie* N.F. 76: 117-146.
- Owen, L. A., 1998. *Timing and Style of Glaciation in the Himalaya* *Himalayan Geology*, Vol. 19(2), pp. 39-47
- Owen, L.A., Sharma M.C., 1998. *Rates and magnitudes of paraglacial fan formation In the Garhwal*

- Himalaya: Implications for landscape evolution Geomorphology*. Vol. 26, Issue 1-3, pp 171+
- Pancheshwar Multipurpose Project 1991. *Field Investigation within Nepal Territory, Final Report Vol II – Site Investigation, Sediment Investigation, Pancheshwar Consortium*, Section 10.
- Pender, M., 1995. *Recent Retreat of the Terminus of Rika Samba Glacier, Hidden Valley, Nepal*. In Wake, C.P. (ed.) *Himalayan Climate Expedition—Final Report*, pp 32–39. Durham, New Hampshire: Glacier Research Group, University of New Hampshire
- Penman 1956. *Evaporation and Introductory Survey*. In *Netherlands Journal of Agricultural Science*, 4: 9–29
- Philip, G., Ravindran, K.V., 1998. *Glacial mapping using Landsat Thematic Mapper Data: A case study in Parts of Gangotri Glacier, NW Himalaya*. *Ind. Jour. Remote Sensing*, 26(1,2), 29-34
- Philip, G., Sah, M.P., 2004. *Mapping Repeated Surges and Retread of Glaciers Using IRS-1C/1D Data: A Case Study of Shaune Garang Glacier, Northwestern Himalaya*. *International Journal of Applied Earth Observation and Geoinformation*. Vol. 6(2), 127-141
- PSIHP, 1991. *Project Direction and Review Report, Pakistan Snow and Ice Hydrology Project*, H and R Directorate, WAPDA, Lahore, Pakistan.
- Puri, V.M.K., Shukla, S.P., 1996. *Tongue fluctuation studies of Gangotri glacier, Uttarkashi District, Uttar Pradesh*. *Geol. Survey of India, Sp. Pub.*, 21(2), 289-91
- Puri, V.M.K., Shukla, S.P., 1995. *Till Fabric Studies in Proglacial Regimen of Gangotri Glacier Uttarkashi District, Uttar Pradesh*. *Proc. Symp. NW Himalaya and Foredeep. Geological Survey of India Sp. Pub.*, 21(2), 1996, pp. 293-298
- Rai, S.C., Sharma, E., 1995. *Landuse change and resource degradation in Sikkim Himalaya*. *Proceedings of 3rd international symposium of Headwater control* 265 – 278p.
- Rai, S.C., Krishnan, A.P., 1996. *Application of remote sensing techniques for monitoring and mapping of land-use/landcover from the Hamley watershed of Sikkim Himalaya, Jr. Development and environmental change in India*, 373-388p.
- Rana B., Nakawo M., Fukushima Y., Ageta Y. 1997. *Application of a conceptual precipitation-runoff model (HYCYMODEL) in a debris Langtans Valley, Nepal Himalaya*. In *Annals of Glaciology*, 25: 226–231
- Rao, D.K., Nizampurkar, V.N., Sam, M.M., 1997. *Accumulation and Flow Rates of ice on Dokriani Bamak Glacier Central Himalayas, based on Radioactive and Stable Isotopes National Symposium on Himalayan Glaciers and Snow Cover- 3-4 March 97*
- Raschid, S., 1995. *Between Two Burrs on the Map-Travels in Northern Pakistan*, Vanguard Books, Lahore.
- Rathur, A.Q., 1987. *Groundwater Management to Eradicate Waterlogging and Salinity in the Upper Indus basin, Punjab, Pakistan*. In *Groundwater and the Environment: Proceedings of the International Groundwater Conference 1987*. Malaysia: Universitiy Kebangsaan. G96-107.
- Rawat, P.V.S., Gairola, B.M., Mukerjee, A., 1999. *Manifestations of Palaeo-Glaciation (Quaternary) in Bhagirathi Valley, Uttarkashi District, U.P.* Abstracts, *Geological Survey of India*, pp 68-69
- Raymond, C. F., 1987. *How do Glaciers Surge? A review*. *J. Geophys. Res.*, 92(B9), 9,121B34.
- Reynolds Geo-Sciences Ltd 1994. *Hazard Assessment at Tsho Rolpa, Rolwaling Himal, Northern Nepal*, Technical Report No: J9402.002 submitted to WECS. Kathmandu, Nepal
- Röthlisberger, F.; Geyh, M.A., 1985. *Glacier Variations in Himalayas and Karakorum*. In *Zeitschrift für Gletscherkunde und Glazialgeologie*, 21: 237–249
- Roy, B. N. and Thapa, M. P. 1998. *Lakes of Sikkim: A Limnological Study*. In Rai, S. C., Sundriyal, R. C. and Sharma, E. (Eds.) *Sikkim: Perspectives for Planning and Development*. Sikkim Science Society and Bishen Singh Mahendra Pal Singh, Dehra Dun: 189-204.

- SAC and SRSAC, 2001. *Glacier atlas of Tista Basin (Sikkim Himalayas)*, Space applications centre (ISRO) Ahmedabad-380015 and State Remote Sensing Applications Centre (State Council of Science and Technology for Sikkim) Gangtok-737101
- Sager, J.W.; Chambers, D.R., 1986. *Design and Construction of the Spirit Lake Outlet Tunnel*, Mount St. Helens, Washington, Special Geotechnical Publication No. 3. New York, USA: ASCE
- Sah, M.P., 1991. *Some geomorphic observations on Badrinath-Satopanth area, Chamoli District, Garhwal Himalaya. Jour. Him. Geol.*, 2(2), 185-195.
- Sah, M.P., 1993. *Himalaya: a spectacular geomorphic feature on the earth. Him. Geo.*, 14, 1-17.
- Sangewar, C.V., Srivastava, D., Singh, R.K., 1999. *Reservoir within the Shaune Garang glacier, District Kinnaur, H.P. Symp. On snow, ice and glaciers. A Himalayan Perspective. Geol. Surv. India, (In: Abst. Vol.), 39-40*
- Searle, M. P., 1991. *Geology and Tectonics of the Karakoram Mountains*, John Wiley, New York.
- Seko, K., Takahashi, S. 1991. *Characteristics of Winter Precipitation and its Effect on Glaciers in the Nepal Himalaya. In Bulletin of Glacier Research*, 9: 9–16
- SFR, 2001. *State of Forest Report 2001. Forest Survey of India, Dehra Dun*, pp.97-99.
- Shafique, M.S. and Skogerboe, G. V. 1984. *Planning and Implementation Framework for Salinity Control in the Indus River Basin. In French, R.H. Salinity in Watercourses and Reservoirs. Proceedings of the 1983 International: Symposium on State-of-the-Art Control of Salinity. Salt Lake City, Utah, 13-15 July 1983. Boston: Butterworth. 93-102.*
- Sharma, H.R., and Sharma, E. 1997. *Mountain agricultural transformation processes and sustainability in the Sikkim Himalayas, India. Mountain Farming Systems, ICIMOD, discussion paper series no. MFS 97/2, 104 pp.*
- Sharma, E.; Sundriyal, R.C.; Rai, S.C.; Bhatt, Y.K.; Rai, L.K.; Sharma, R.; and Rai, Y.K., 1992. *Integrated watershed management: A case study in Sikkim Himalaya. G.B.Pant Institute of Himalayan Environment and Development by Gyanodaya Prakashan Nainital, HIMAVIKAS Publication No.2, 120pp.*
- Sharma, M.C., Owen, L.A., 1996. *Quaternary glacial history of the Garhwal Himalaya, India. Quat. Sci. Review*, 15, 335-365
- Sharma, R., Paul, S.K., 2002. *The mineralization in Uttaranchal: An Overview. In N.K. Verma (Ed.) Proceeding national Workshop on “Natural Wealth of Uttaranchal” Pp. 171-188.*
- Shankar, K., Shrestha P.B 1985b. ‘*Water Resources*’. In Majupuria, T.C. (ed.) *Nepal—Nature’s Paradise*, pp 25–32. Bangkok: White Lotus
- Shankar, K., Shrestha P.B. 1985a. ‘*Climate*’. In Majupuria, T.C. (ed.) *Nepal—Nature’s Paradise*, pp 39–44. Bangkok: White Lotus
- Shifeng, Y. and Wang, W. 1980. *Research on Snow-Cover in China and the Avalanche.*
- Shiraiwa, T., 1993. *Glacier Fluctuations and Cryogenic Environments in the Langtang Valley, Nepal Himalaya*, contributions from the Institute of Low Temperature Science, Series No. 38. Sapporo: The Institute of Low Temperature Science, Hokkaido University
- Shrestha, A.B., Wake, C.P., Dibb, J.E. 2000. *Precipitation Fluctuations in the Himalaya and its Vicinity: An Analysis Based on Temperature Records from Nepal. In International Journal of Climate*, 20: 317–327
- Shrestha, A.B., Wake, C.P., Mayewski, P.A., Dibb, J.E. 1999. *Maximum Temperature Trends in the Himalaya and its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971–94. In Journal of Climate*, 12: 2775–2787
- Shrestha, H.M., 1965. *Our Rivers—A Preliminary Study in Gokhaptra (Magh 23, 2022)*
- Shrestha, H.M., 1966. *Cadastré of Hydropower Resources of Less-studied High Mountainous Regions (in the example of Nepal)*
- Shrestha, H.M., 1968. *Water Power Potential of Nepal (its Theoretical and Technical limitations). In Transactions of VII World Power Conference*

- Shrestha, H.M., 1985. *Water Power Potential*. In Majupuria, T.C. (ed.) *Nepal—Nature's Paradise*, pp 32–38. Bangkok: White Lotus
- Shrestha, H.M., 1995. *Hydropower in WECS*, Supporting Document No. 2, Energy Perspective Plan
- Shukla, S.P., Siddiqui, M.A., 1999. *Recession of the snout front of Milam Glacier, Goriganga valley, District Pithoragah, Uttar Pradesh*. Symp. on snow, ice and glaciers. A Himalayan Perspective. Geol. Surv. India, (In: Abst. Vol.), 27-29
- Singh, I.L. 1985. *Rainfall Distribution*. In Majupuria, T.C. (ed.) *Nepal—Nature's Paradise*, pp 56–58. Bangkok: White Lotus
- Srivastava, D., Shukla S.P., Bajpai, V.N., 1999. *Status of Glaciological Studies by Geological Survey of India*. In Uttar Pradesh Himalaya Geological Survey of India, Lucknow, Shillong. Abstracts, *Geological Survey of India*, pp 2-4 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Srivastava, D., Swaroop,S., Mukerji, S., Roy D., Gautam, C.K., 1999. *Mass Balance of Dunagiri Glacier, Chamoli District, Uttar Pradesh*. Abstracts, *Geological Survey of India*, pp 10-11. Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Srivastava, D., Swaroop, S., 1999. *Oscillations of snout of Dunagari Glacier. Symposium on Snow, Ice and Glaciers a Himalayan Prespective*. Abstracts p.34. Organised by G.S.I., Lucknow
- Srivastava, D., Swaroop, S., Mukerji, S., Gautam, C.K., Roy, D., 1999. *Suspended sediment yield and its variation in Dunagari Glacier melt stream, Garhwal Himalaya. Symposium on Snow, Ice and Glaciers a Himalayan Prespective*. Abstracts p.45. Organised by G.S.I., Lucknow
- Survey of Pakistan, 1997. *Atlas of Pakistan*. Pp.143.
- Swaroop, S., Oberoi, L.K., Srivastava, D., Gautam, C.K., 1999. *Recent fluctuations in Snout front of Dunagiri and Chaurabari Glaciers, Dhauliganga and Mandakini -Alaknanda Basins, Chamoli District, Uttar Pradesh*. Abstracts, *Geological Survey of India*, pp 29-30
- Swain, P.H., and Davis S.M., 1979. *Remote sensing: The Quantitative Approach*. USA: McGraw-Hill.
- Swaroop, S., Srivastava, D., 1999. *Predictive significance and Interdependence of Glacier Discharge, Ablation and Microclimatic Elements on Dunagiri Glacier, Chamoli District, Uttar Pradesh*. Abstracts *Geological Survey of India*, pp 05 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Swaroop, S., Srivastava, D., Roy, D., Gautam, C.K., 1999. *Variation Pattern of vertical and emergent flow components of velocity and change in Glacier thickness along the altitudinal profile of Dunagiri Glacier, Chamoli District, U.P*. Abstracts, *Geological Survey of India*, pp 7-8 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Tanaka, Y., Ageta, Y., Higuchi, K. 1980. *Ice Temperature Near the Surface of Glacier AX010 in Shorong Himal, East Nepal*. In Seppyo, *Journal of the Japanese Society of Snow and Ice*, 41(4): 55–61 (special issue)
- Tangri, A. K., 1999. *Physico-Chemical and Hydrological Characteristics of Melt-Waters of Himalayan Glaciers, North of Badrinath, in Chamoli District of Uttar Pradesh, India* Abstracts, *Geological Survey of India*, pp 54-55 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Tewri, A. P., 1999. *Note on the Maiktoli -Burhgal Glaciers, Almora District, Kumaon Himalayas, Uttar Pradesh*. Abstracts, *Geological Survey of India*, 1999, pp 106-107 Symposium on Snow, Ice and Glaciers- A Himalayan Perspective, Lucknow 9-11 March 99
- Tewari, A.P., 1999. *A study of the Mrigthuni Glacier, Almora District, Kumaon Himalayas, Uttar Pradesh*. Abstracts, *Geological Survey of India*. pp 102 *Symposium on Snow, Ice and Glaciers- A Himalayan Perspective*, Lucknow 9-11 March 99
- Thakur, V.C., Viridi, N.S., Gergan, J.T., Mazari, R.K., Chaujar, R.K., Bartarya, S.K., Philip, G.,

1991. *Report on Gaumukh. The snout of the Gangotri glacier* (Unpublished Report submitted to DST, New Delhi)
- Thayyen, R.J., Gergan, J.T., Dobhal, D.P., 1999. *Temporal variations in Particle Size Characteristics of Suspended Sediments and Glacial Drainage of Dokriani Glacier, Garhwal Himalaya*. Abstracts, *Geological Survey of India*, pp 47-49 *Symposium on Snow, Ice and Glaciers- A Himalayan Perspective*, Lucknow 9-11 March 99
- Thornthwaite, C.W., 1948. *An Approach Towards Rational Classification of Climate*. In: *Geographical Review*, 38: 55–94
- Valdiya, K.S., 1980. *Geology of Kumaun Lesser Himalaya*. Wadia Institute of Himalayan Geology, Publication. pp 291.
- Verlag; Knorr; and Hirth M. 1932. *Digitized topographic map of Zemu glacier area from the map Karte Des Zemu - Gletschers surveyed by Deutsche Himalaja – Expedition in 1931* (II Bauersche Expedition)
- Vohra, C.P., 1981. *Note on recent glaciological expedition in Himachal Pradesh Geol. Survey of India Spec. Publ.*, 6, 26-29.
- Vohra, C. P., 1988. *Himalayan glaciers*. In: *Himalayan Aspects of Change*, Lall, J.S. and Maddi, A.D. (Eds.) *Oxford University Press*, Delhi, pp138-151
- Vohra, C.P., Aggarwal, N.K., 1981. *Glacier inventory from satellite imagery in a Himalayan situation*. *Zeitschrift fur Gletscherkunde und Glazialgeologie*, 17, 199-204
- von Klebelsberg, 1925B6. *Der Turkestanische Gletschertypus*, *Zeitschrift für Gletscherkunde*, 14, 193B209.
- Vuichard, D., Zimmerman, M. 1986. *The Langmoche Flash Flood, Khumbu Himal, Nepal*. In *Mountain Research and Development*, 6(1): 90–94
- Vuichard, D.; Zimmerman, M., 1987. *The 1985 catastrophic drainage of a moraine-dammed lake, Khumbu Himal, Nepal: Cause and consequence*. In *Mountain Research and Development*, 7(2): 91–110
- Wadia D. N., 1957. *Geology of India*, 3rd Ed., *Macmillian*, London. 531 pp.
- WAPDA, 1976. *Sediment Appraisal of West Pakistan Rivers 1966-75*, *Pakistan Water and Power Development Authority*, Lahore.
- Watanabe, O. 1976. *On the Types of Glaciers in the Nepal Himalayas and Their Characteristics*. In *SEPPYO*, 38, 10-16
- Watanabe, T., Ives, J.D., Hammond, J.E. 1994. *Rapid Growth of a Glacial Lake in Khumbu Himal, Himalaya: Prospects for a Catastrophic Flood*. In *Mountain Research and Development*, 14(4): 329–340.
- Watanabe, T., Kameyama, S., Sato, T. 1995. *Imja Glacier Dead-Ice Melt Rates and Changes in a Supra-glacial Lake, 1989-1994, Khumbu Himal, Nepal: Danger of Lake Drainage*. In *Mountain Research and Development*, 15(4): 293–300
- Wavin Overseas B.V., 1996. *Trial Siphon at Lake Tso Rolpa, Report on Siphon Installation (Tsho Rolpa/JVN)*, submitted to WECS, Kathmandu, Nepal
- WECS 1987a. *Erosion and Sedimentation in the Nepal Himalaya, an Assessment of River Process*, WECS Report No. 4/3/010587/1/1, Seq. No. 259. Kathmandu, Nepal: WECS
- WECS 1987b. *Study of Glacier Lake Outburst Floods in the Nepal Himalayas, Phase I, Interim Report, May, 1997*, WECS Report No. 4/1/200587/1/1, Seq. No. 251. Kathmandu, Nepal: WECS
- WECS 1991. *Preliminary Work Report on Glacier Lake Outburst Flood in the Nepal Himalayas*, WECS Report No. 4/1/291191/1, Seq. No.387. Kathmandu, Nepal: WECS/JICA
- WECS 1993a. *Interim Report on the Field Investigation on the Tsho Rolpa Glacier Lake, Rolwaling Valley*, WECS Report No. 3/4/021193/1/1, Seq. No. 436. Kathmandu, Nepal: WECS

- WECS 1993b. *Preliminary Report on the First Field Investigation on the Lower Barun Glacier Lake*, WECS Report No. 3/4/080893/1/1 Seq. No.428. Kathmandu, Nepal: GLOF Unit, WECS
- WECS 1994. *Report for the Field Investigation on the Tsho Rolpa Galcier, Rolwaling Valley, February 1993–June 1994*, WECS N551.489 KAD. Kathmandu, Nepal: WECS
- WECS 1995a. *Data Report, Meteorological and Hydrological Data at Tsho Rolpa Glacier Lake, Rowaling Himal—From June 1993 to May 1995*, WECS N551489 DAT. Kathmandu, Nepal: WECS
- WECS 1995b. *Electrical Resistively Exploration at Tsho Rolpa End Moraine*, WECS N551.489 OYO. Kathmandu, Nepal: WECS
- WECS 1995c. *Preliminary Report on the Thulagi Glacier Lake, Dhana Khola, Marsyangdi Basin*, WECS Report No. 473, Seq. No. 2/3/170795/1/1. Kathmandu, Nepal: WECS
- WECS 1995d. *Report on Tsho Rolpa Glacier Lake Field Visit in Rolwaling Himal—Post-monsoon Season, 1995*, WECS N551.489 WAT. Kathmandu, Nepal: WECS
- WECS 1995e. *The Debris Flow and the Hazard due to GLOF in the Rolwaling Valley, Nepal*, WECS N551.489 FUJ. Kathmandu, Nepal: WECS
- WECS 1996. *Report on the Investigations of Tsho Rolpa Glacier Lake, Rolwaling Valley*. WECS/JICA
- WECS 1997. *Study and Topographic Mapping of Lower Barun Glacier Lake, Vol 1*. Kathmandu, Nepal: WECS
- WECS 1999. Nepal Energy Supply Demand Balance. In WECS Bulletin, 10(1/2)
- WGMS 1989. *World Glacier Inventory, Status 1988*, a contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme, compiled by the *World Glacier Monitoring Service (WGMS)*. IAHS (ICSU), UNEP, UNESCO
- WGMS 1998. *Fluctuations of Glaciers, 1990–1995, Vol. VII*, a contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme; compiled by the *World Glacier Monitoring Service (WGMS)*. IAHS (ICSU), UNEP, UNESCO
- Whiteman, Peter T.S., 1985. *Mountain Oases: a Technical Report of Agricultural Studies (1982-1984) in Gilgit District, Northern Areas, Pakistan*. Islamabad, Pakistan: United Nations Development Program/Food and Agriculture Organization of the United Nations.
- Williams, R.S. (Jr.), Hall, D.K., Benson, C.S., 1991. *Analysis of glacier facies using satellite techniques*, *Journal of Glaciology*, 37(125), 120-128
- Williams, G.P., 1988. *Paleofluvial Estimates from Dimensions of Former Channels and Menders*. In Baker, V.R., Kochel, R.C., Patton, P.C. (eds) *Flood Geomorphology*, pp 321–334. New York: Wiley Interscience.
- Williams, V.S., 1983. *Present and Former Equilibrium Line Altitudes near Mount Everest, Nepal and Tibet*. In *Arctic and Alpine Research*, 15: 201–211
- Williams, V.S. 1988. *Present and Former Equilibrium Line Altitudes near Mount Everest, Nepal and Tibet*. In *Arctic and Alpine Research*, 15: 201–211
- Wissman H. Von., 1959. *The Present Day Glacier Cover and Snowline in High Asia*. *Akad. D. wiss. Und.d. Litt.* 14: 1101-1436.
- XuDaoming 1985. *Characteristics of Debris Flows Caused by Outbursts of Glacier Lakes in Boqu River in Xizang, China, 1981*. *Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica*
- Yamada, T., 1992. *Report for the First Research Expedition to Imja Glacier Lake – 25 March to 12 April 1992*, WECS Report No. 3/4/120892/1/1, Seq. No. 412. Kathmandu, Nepal: WECS/JICA
- Yamada, T., 1993. *Glacier Lakes and their Outburst Floods in the Nepal Himalaya*. Kathmandu, Nepal: WECS

- Yamada, T., 1998. *Glacier Lake and its Outburst Flood in the Nepal Himalaya*. Data Center for Glacier Research, *Japanese Society of Snow and Ice*
- Yamada, T., Shiraiwa, T., Iida, H., Kadota, T., Watanabe, T., Rana, B., Ageta, Y., Fushimi, H. 1992. *Fluctuations of the Glaciers from the 1970s to 1989 in the Khumbu, Shorong and Langtang Regions, Nepal Himalayas*. In *Bulletin of Glacier Research*, 10: 11–19
- Zhang, Jinhua and Bai Zhongyan., 1980. *The Surface Ablation and its Variation on the Batura Glacier*. In Shi Yofeng (ed.) *Papers on the Batura Glacier, Karakoram Mountains*. Beijing Sci. Press 83-98.
- Zhang, X., and Shifeng, W., 1980. *Changes in the Batura Galcier in the Quaternary and Recent Times*, In, *Professional Papers on the Batura Glacier*, (Ed Shifeng, W.)
- Zheng, Q., Cao, C.M., Feng, X., Liang, F., Chen, X., Sheng, W., 1984. *Study on spectral reflection characteristics of snow, ice and water of northwest China*, *Science Sinica (Ser. B)*, 27, 647-65
- Zimmermann, M., Bichsel, M., Kienholz, H. 1986. *Mountain Hazards Mapping in the Khumbu Himal, Nepal, with prototype map, scale 1:50,000'*. In *Mountain Research and Development*, 6(1): 29–40