

## Information series on geographical information and remote sensing systems in mountain environments

Geographical information and remote sensing systems play a special role in the Hindu Kush-Himalayan region in support of informed decision making. This series of information sheets presents information on basic technologies, approaches, and applications related to geographical information and remote sensing, and used or developed by ICIMOD, as a background for understanding for policy makers, development workers, and others.

The Hindu Kush-Himalayas have the largest area of snow and glaciers outside the polar regions. Mapping and inventorying such a large number of glaciers over such a vast territory is a massive undertaking, but the information is essential in order to be able to draw clear scientifically justified conclusions about any climatic changes that are occurring. Since its inception, ICIMOD's GIS/RS Division, MENRIS, has mapped snow and glacier cover in the Hindu Kush-Himalayan region, completing the first ever regional-level inventory of glaciers in 2004. This first inventory was, for the most part, completed by extracting information from topographic maps and processing manually. The baseline study was a good first step, but in order to detect differences and variations monitoring needs to continue on a regular basis. By the end of 2010, the second inventory will have been completed. This second inventory represents a marked improvement on the first, since it builds on the use of remotely sensed data, which are now more widely available. Advances in the software for analysing such data have made it easier to extract information on glaciers more quickly and accurately.

# Glacier Mapping and Monitoring

## Tools and techniques

### What the baseline survey found

Data from glaciers in different areas, of different size, and at different altitudes in the Himalayas were summarised and refined in collaboration with partners United Nations Environment Programme (UNEP), Asia-Pacific Network for Global Change Research (APN), SysTem for Analysis, Research and Training (START), and national collaborating agencies in ICIMOD's regional member countries. The first study was conducted from 1999 to 2004 and generated important baseline information about glaciers based on the World Glacier Monitoring Service (WGMS) attribute list. It included the Hindu Kush-Himalayan countries of Bhutan, Nepal, Pakistan, the Ganges Basin in the Tibet Autonomous Region of China, and selected river basins in India (Tista River basin, Himachal Pradesh, and Uttarakhand). The study identified more than 15,003 glaciers within the surveyed area of 33,344 sq.km. The work suggested that the majority of glaciers in the region were in a general condition of retreat, although with some differences in a few basins.

Some important institutions in glacier monitoring

The **World Glacier Monitoring Service (WGMS)** has collected standardised observations since 1894 on changes in mass, volume, area, and length of glaciers with time (glacier fluctuations), as well as statistical information on the distribution of perennial surface ice in space (glacier inventories).

**GlobGlacier** projects attempt to establish a service for glacier monitoring from space, with the aim of establishing a global picture of glaciers and ice caps, and their role as essential climate variables.

**Global Land Ice Measurements from Space (GLIMS)** is a project designed to monitor the world’s glaciers primarily using data from optical satellite instruments.

Landsat satellite image to delineate clean ice and debris-covered glaciers



Change of glacier cover, Dudh Koshi basin 1970 to 2000



New developments in data analysis and methodology

A new inventory of the status of snow and ice at the regional level is needed at least once a decade to study changes. Mapping and monitoring of glaciers has become easier with the advent of more readily available remote sensing data. It is now possible to use state-of-the-art multi-spectral (optical) satellite image analysis for automated/semi-automated mapping of clean ice or (C-type) and debris covered (D-type) glaciers in the region. The attribute parameters are for the most part derived from satellite images and digital elevation models using Arc GIS software.

Updating the regional inventory of glaciers using new tools

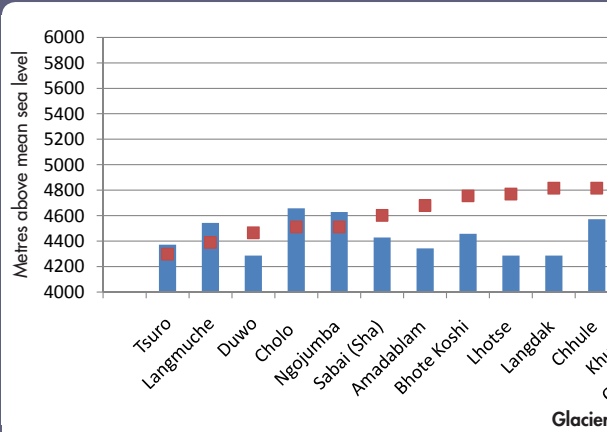
Work is underway to update the glacier mapping and inventory for Afghanistan, Bhutan, Myanmar, and Nepal, and to compile glacier inventory data for China, India, and Pakistan by the end of 2010. In keeping with the latest methods, the attribute data for the 2010 study are based on the 2009 ‘Guidelines for the compilation

Results of first Himalayan region glacier inventory

River basin/area	Glaciers		
	Number	Area (km²)	Ice reserve (km³)
Indus River (Pakistan)*	5,218	15,041	2,739
Himachal Pradesh (India)*	2,554	4,161	387
Uttarakhand (India)*	1,439	4,060	475
Nepal**	3,252	5,324	481
Ganges (TAR of China)*	1,578	2,864	NA
Tista River (India)*	285	577	
Bhutan**	677	1,317	127
Total	15,003	33,344	NA

\* based on satellite images from 1999 to 2001  
\*\* based on topographic maps published from 1963 to 1982, satellite images from 1999 and 2000 used where topographic maps not available

Glacier retreat in the Dudh Koshi

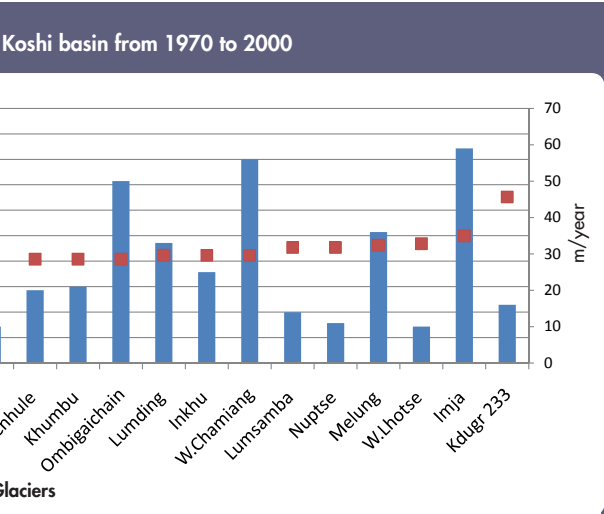


of glacier inventory data from digital sources’. These guidelines are world standard and have been reviewed and accepted by several international members and user groups of the GlobGlacier and GLIMS communities. Fine tuning, such as determining the boundary of debris-covered glaciers, or classifying and finding the maximum length of glaciers, is done manually based on interpretations by glaciologists.

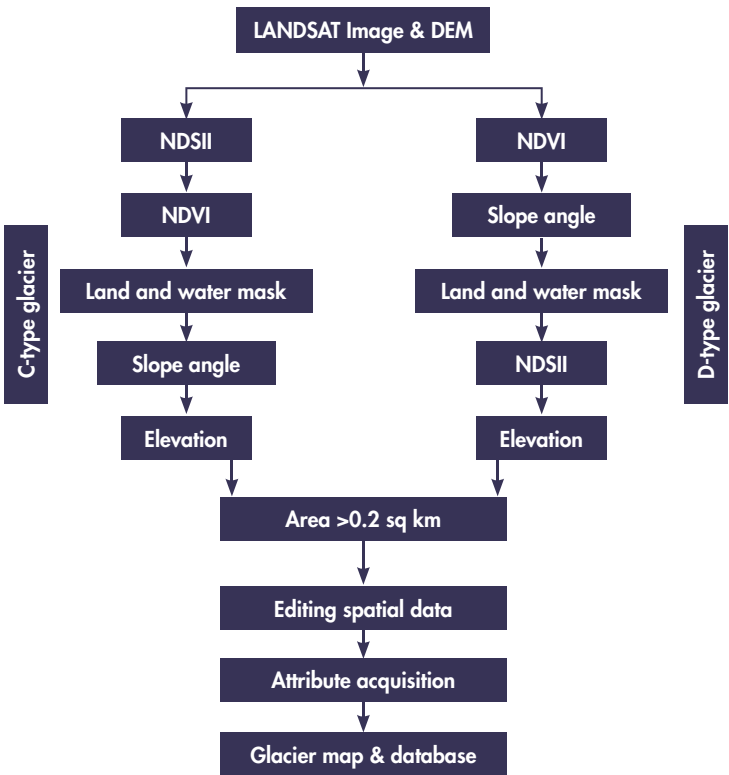
The new study will be an improvement over the previous study for several reasons, especially the following:

- The study uses homogenous glacier data derived from a single source (multi-spectral Landsat satellite data) and acquired over a very narrow time window (2007-2009), whereas the previous study used topographic maps collected over decades. The disadvantage of topographic maps is that they are not digital and not always available over the entire mapping area for the same time period. When data from widely varying time periods are used, there is a risk that the glaciers could have evolved making comparisons problematic.
- The remote sensing data used in the study are available in the public domain and can be downloaded freely. Anyone wishing to access the raw data to repeat the measurements or make additional ones in a specific area can readily do so.
- The mapping of clean ice glaciers is automated and the mapping of debris-cover glaciers is semi-automated using the appropriate algorithms. Even when this mapping is supplemented by existing and analytical parameters it is much quicker than the manual methods previously used and inaccuracies are avoided.

The efficient data compilation using advanced software tools and technologies means that much more detailed information can be extracted and catalogued.



Flowchart for generating a map of clean ice and debris cover glaciers

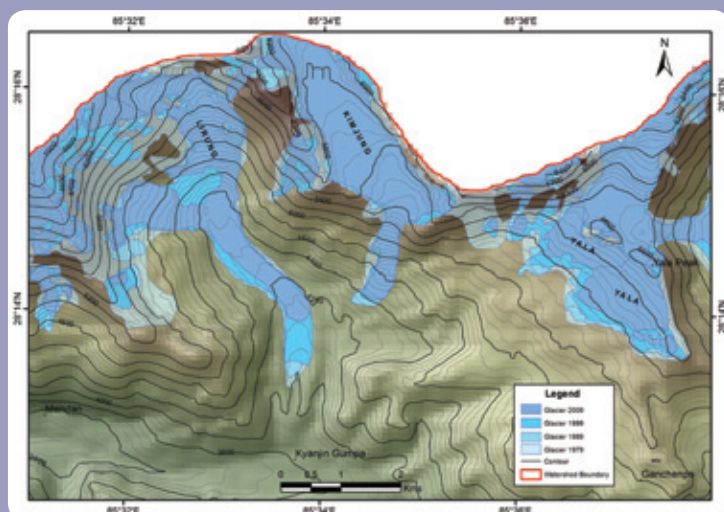


The mapping of glaciers is based on the following parameters: NDSII (Normalised Difference Snow and Ice Index); NDVI (Normalised Difference Vegetation Index); NDWI (Normalised Difference Water Index); Slope (less than 60 degrees); Elevation (above 3300 masl); Area (greater than (0.02 sq.km)

#### Glacier attribute parameters before and after automated mapping

2001 study based on WGMS	2010 study based on WGMS, GLIMS and GlobGlacier
Glacier ID	Glacier ID
Glacier name	GLIMS ID
Latitude	Glacier name
Longitude	Latitude
Total area	Longitude
Map code 1960s	Clean ice area
Map code 1996s	Debris covered area
Aerial photo number	Total glacier area
Image number	Maximum length
Max length (km)	Orientation of clean ice
Orientation accumulation	Orientation of debris cover
Orientation ablation	Highest elevation of ice
Highest elevation	Lowest elevation of ice
Mean elevation	Highest elevation of debris cover
Elevation of tongue	Lowest elevation of debris cover
6 digit classification	Mean elevation
Mean thickness	Average slope of clean ice
Reserves of ice	Average slope of debris cover
	6 digit classification
	Morphological classification
	Average thickness
	Reserve of ice





Glacier retreat in the Langtang Valley 1979 to 2009



Kirung glacier in the Langtang Valley

## The way forward

Mountain systems have recently attracted unprecedented global attention because of the vulnerabilities highlighted by receding glaciers and growing glacial lakes, which are the most spectacular indicators of climate change. Climate change is producing greater temperature changes at higher altitudes and most glaciers in the Hindu Kush-Himalayan region are shrinking and retreating rapidly. Observations of individual glaciers indicate that annual retreat rates vary between basins. In some instances, they have doubled in recent years compared to the early 1970s. It is important to improve our understanding of the dynamics of the cryosphere, and especially to document the status of glaciers in the Hindu Kush-Himalayan region, as they are global markers of climate change. The use of remote sensing data and techniques and geographic information system (GIS) data, complemented by field verification, is an effective method for the mapping and inventorying of glaciers in the region. These methods are continuously improving and converging so that it becomes increasingly easy to compare and exchange data worldwide.

## Further reading

- Bajracharya, SR and PK Mool (2009) *Glaciers, glacial lakes and glacial lake outburst floods in the Everest region*. Nepal. Annals of Glaciology, 50 (53) London, UK. 81 – 86pp.
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