Space Science for Himalayan Ecosystem Development in India

PS Roy, Director, Indian Institute of Remote Sensing, Indian Space Research Organization (ISRO), Dehradun, India, psr@iirs.gov.in; psroy13@gmail.com
V Jayaraman, Satish Dhawan Professor, ISRO, and Senior Advisor (Space Applications), vjay202@gmail.com

Sustainable development of mountain ecosystems is a challenge in the context of rapid global change. Increased water discharge from melting glaciers associated with increased precipitation, deforestation, grazing, and human disturbances has resulted in increased erosion in the world's mountain regions, including the Hindu Kush-Himalayan (HKH) region. Deforestation, combined with the region's geotectonic composition and precipitation, has resulted in an increased incidence of landslides in most of the Himalayan mountain ranges. As a result, huge amounts of surface soil have been washed into the region's streams and rivers.

In addition, traditional land use is changing quickly in the HKH, influenced by globalisation. Land use intensification is a severe threat to the mountain environment. The Himalayan mountains are particularly susceptible to climate change impacts, which are often coupled with anthropogenic changes to mountain landscapes associated with population changes and economic activities. The region's political and economic marginalisation creates added vulnerability because of the reduced capacity to adapt to such changes. Changes in the bioclimatic envelope will lead to changes in land use regimes and hydrological cycles. Changes in land use and land cover regimes will also affect the tourism industry, which will change the human footprint in the mountains.

With a vast population dependent on mountain resources for their livelihood, regular monitoring of the landscape is required for proper planning and execution of sustainable d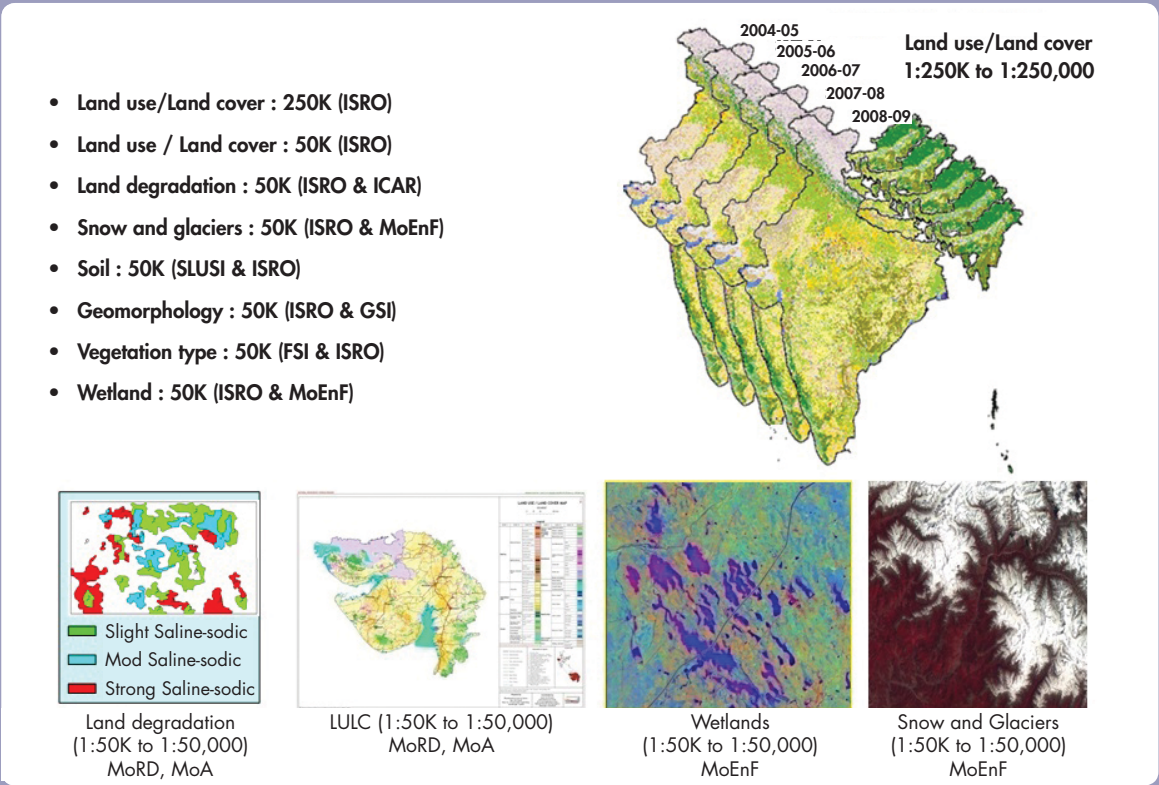evelopment initiatives in the face of a mounting resource crunch. Considering the heterogeneity and spatial variability in mountain ecosystems, space-based satellite remote sensing, with its synoptic and temporal viewing potential, can provide reliable information for planning and decision making.

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Remote sensing and geographic information systems (GIS) play an important role in providing spatially explicit information on land, the atmosphere, and the environment. As part of India's national Natural Resources Census, the Indian Space Research Organization (ISRO), in collaboration with other organisations, is generating seven spatial databases on different natural resource themes using space-based inputs (Figure 1). These spatial databases are on land use and land cover at 1:250 and 1:50,000; land degradation; snow and glaciers; soils; geomorphology; vegetation type (Figure 2); and wetlands. The spatial data can be modelled in a GIS environment to predict probable land use and land cover change (Figure 3) (Roy and Roy 2010).

Remote sensing also provides spatial data on aerosol distribution and movement, which can be used to predict the movement of pollutants and their deposition. Integrating satellite remote sensing-based spatial data with global circulation models will help in modelling the nutrient loading on ecosystems. The global coverage of the various space-based platforms permits the availability of temporal data, for example on sea surface temperature changes and climatic processes such as El Niño, that are useful in modelling the impact of

Figure 1: **India's national Natural Resources Census database using space-based inputs**

- Land use/Land cover : 250K (ISRO)
- Land use / Land cover : 50K (ISRO)
- Land degradation : 50K (ISRO & ICAR)
- Snow and glaciers : 50K (ISRO & MoEnF)
- Soil : 50K (SLUSI & ISRO)
- Geomorphology : 50K (ISRO & GSI)
- Vegetation type : 50K (FSI & ISRO)
- Wetland : 50K (ISRO & MoEnF)

2004-05
2005-06
2006-07
2007-08
2008-09

**Land use/Land cover
1:250K to 1:250,000**

Slight Saline-sodic
Mod Saline-sodic
Strong Saline-sodic

Land degradation
(1:50K to 1:50,000)
MoRD, MoA

LULC (1:50K to 1:50,000)
MoRD, MoA

Wetlands
(1:50K to 1:50,000)
MoEnF

Snow and Glaciers
(1:50K to 1:50,000)
MoEnF

FSI: Forest Survey of India; GSI: Geological Survey of India; ICAR: Indian Council of Agricultural Research; ISRO: Indian Space Research Organization; LULC: land use and land cover; MoA: Ministry of Agriculture; MoEnF: Ministry of Environment and Forest; MoRD: Ministry of Rural Development; SLUSI: Soil and Land Use Survey of India;

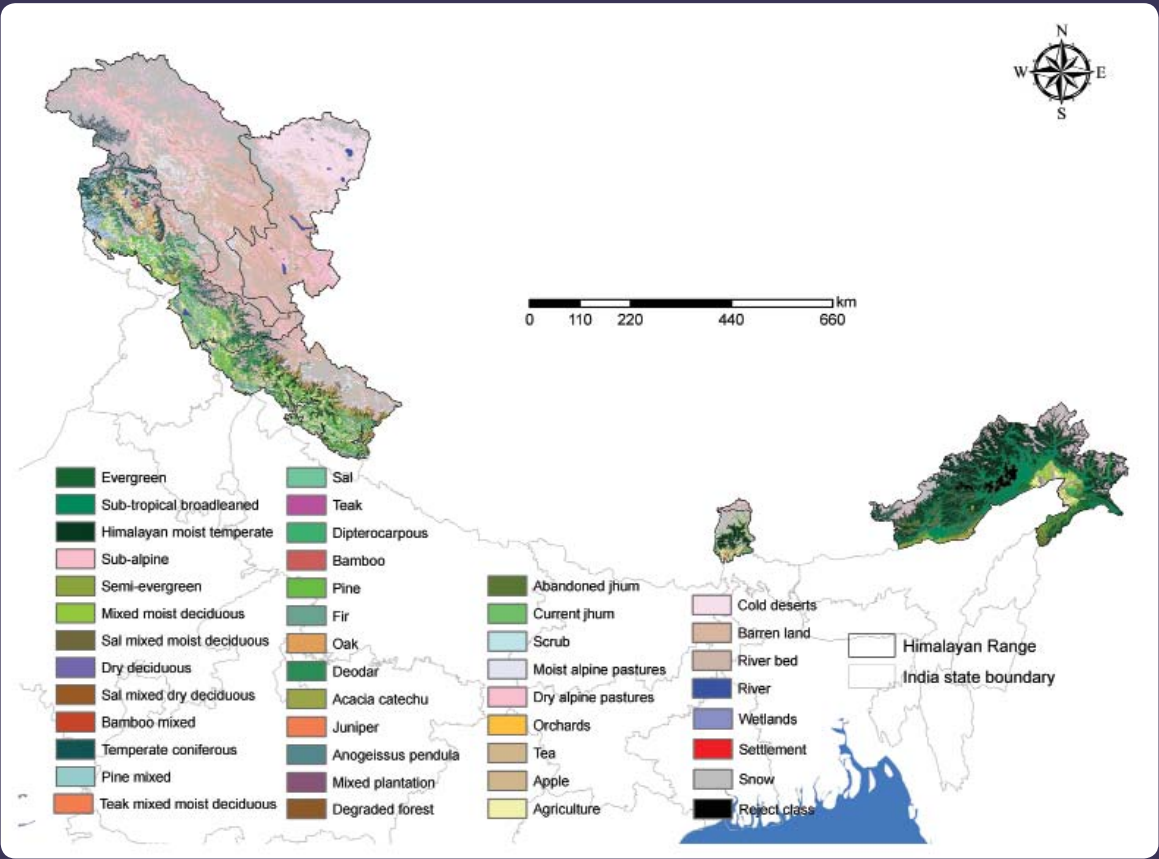Figure 2: **Vegetation type and land use map of the Indian Himalayas**

Evergreen
Sub-tropical broadleaned
Himalayan moist temperate
Sub-alpine
Semi-evergreen
Mixed moist deciduous
Sal mixed moist deciduous
Dry deciduous
Sal mixed dry deciduous
Bamboo mixed
Temperate coniferous
Pine mixed
Teak mixed moist deciduous

Sal
Teak
Dipterocarpous
Bamboo
Pine
Fir
Oak
Deodar
Acacia catechu
Juniper
Anogeissus pendula
Mixed plantation
Degraded forest

Abandoned jhum
Current jhum
Scrub
Moist alpine pastures
Dry alpine pastures
Orchards
Tea
Apple
Agriculture

Cold deserts
Barren land
River bed
River
Wetlands
Settlement
Snow
Reject class

Himalayan Range
India state boundary

Figure 3: **Modelled land use and land cover map of Goa, India for the year 2027 using agent-based modelling**
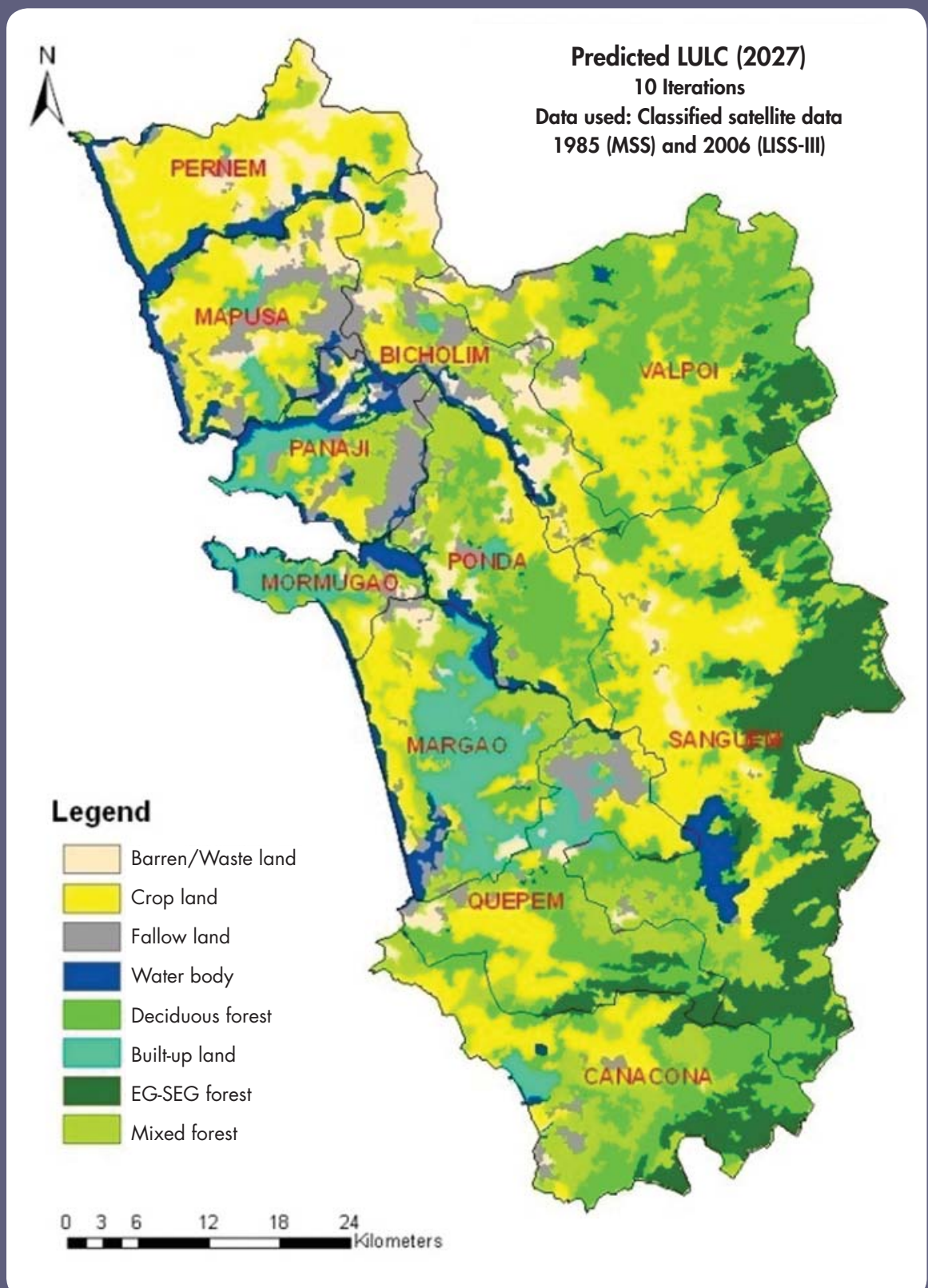
ISRO projects using Earth observation systems to support the sustainable development of mountain ecosystems

Project	Sensors used	Contribution
Ongoing		
Landslide hazard zonation	Microwave, LISS III, Cartosat	Identification of potential areas for landslide occurrence
Hydrological modelling	Cartosat, LISS III, LISS I, MSS	Estimates of the total hydrological cycle of a watershed and carrying capacity of a region; input for LULCC
Glacier retreat	Microwave, LISS III, LISS I, MSS	Estimates of dwindling fresh water resources for their sustainable use
NAPCC (Sustaining Himalayan Ecosystem)	SRTM-DEM, ASTER-DEM, LISS III	Decision support tools and information for sustaining the fragile Himalayan ecosystem, targeting food, water, and energy security
Biodiversity characterisation at landscape level	LISS III	Identification of India's biologically rich areas for conservation
Impact of global change on species and habitat transition	LISS III, LISS I, MSS	Generation of probable scenario of species and habitat transition due to global change
LULC dynamics and impact of human dimensions in the river basins	LISS III, LISS I, MSS	Generation of LULC scenario for 2025 and 2050 considering anthropogenic pressures on the major river basins of India
Yearly LULC assessment (1:250,000) as part of Natural Resources Census	AWiFS	Information on annual cropping patterns of rabi, kharif, and zaid along with land cover such as snow
Carbon pool assessment	LISS III,	Identification of potential carbon pool in above-ground and below-ground biomass and soil
Future		
Use of CartoDEM tmodelling probable hydro-electric power generation sites	Cartosat I & II	Identification of the size and scope of hydropower generation capacity in the region for clean energy
Ecological impact assessment of hydro-electric power projects	Cartosat I & II, LISS IV	Estimation of the social and ecological impact of creating major hydro-electric projects
Impact of climate change on tree line shifts	Cartosat, LISS III, LISS I, MSS	Identification of changes in the tree line and in flowering and fruiting of high-altitude flora as a result of climate change
Assisted vegetation regeneration in landslide affected areas	Microwave, LISS IV, Cartosat	Identification of landslide regions to target for vegetation re-growth through assisted regeneration, to prevent further erosion
Early warning system for glacial lake outburst flood	Microwave, LISS IV, Cartosat - DEM, 24x7 videography	Protection of life and property downstream from glacial lakes

Notes: LISS: Linear Imaging Self Scanner; MSS: Multispectral Scanner; NAPCC: National Action Plan for Climate Change; LULC: land use and land cover; LULCC: land use and land cover change

climate change in the spatial domain. With the development of new technologies in light detection and ranging (LIDAR), hyperspectral, and microwave-based sensors, the spatial characterisation of the various facets of climate change and its impacts will become easier, enabling appropriate steps in mitigation.

Geospatial technology has revolutionised the modelling of hydrological runoff from watersheds, and space-based inputs play an important role in this process, mainly in the form of data on temporal land use and land cover. It has been well documented that land use and land cover alteration coupled with climate change can result in substantial changes in hydrological and watershed processes (Bosch and Hewlett 1982; Foley et al. 2004; Gao et al. 2010). It is of utmost importance that probable changes in hydrological regimes as a result of various development activities in mountainous regions be modelled, as these changes could have adverse impact on the livelihoods of more

than 3 billion people. The Table shows many examples of how ISRO is using Earth observation systems to promote the sustainable development of the Indian mountain ecosystems.

Outlook

Satellite remote sensing, GIS, satellite positioning systems, and many other technological advances such as broadband connectivity, networking, and enhanced computing capabilities should pave the way for new products and services that can be used in addressing the specific issues facing mountain ecosystems. The Natural Resources Census has done a tremendous amount of work in generating natural resource databases for India using space-based remote sensing inputs. These databases can help in quick estimation of the regions affected by change, and in some cases can help identify probable regions of change.

Countries in the HKH region have started working on their own national adaptation programmes of action to address climate change. The Government of India, for example, has included 'Sustaining Himalayan Ecosystem' as one of the eight missions in its National Action Plan for Climate Change (NAPCC), launched in 2009. In this regard, there is much discussion, including in the Global Earth Observation System of Systems (GEOSS), as to how to integrate satellite-based Earth observation systems and in situ observations to capture essential climate variables in a more quantifiable manner and capture the benefits in climate change adaptation and disaster risk reduction strategies.

Space-based inputs, with their unbiased and synoptic coverage of spatial variability, coupled with their ability to generate a temporal database, provide an indication of the intensity, rate, and extent of the changes taking place in the landscape. With GIS and modelling capabilities, the ability to predict the probable impact of climate change on mountain landscapes greatly increases. Space-based technology is thus an important tool for planning and implementing strategies to address food, water, and energy security in the HKH region (Figure 4).

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Figure 4: **Space-based inputs to support sustainable development of mountain ecosystems**