


Chapter 1

Earth Observation Applications in the Hindu Kush Himalaya Region—Evolution and Adoptions



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1.1 Introduction and Rationale

The year 1957 marked the start of a new era in human history with the launch of Sputnik, thus began the journey of Earth observation (EO). Then, in the early 1960s, with rapid developments in space technology and the race to reach the moon, scientific discussions veered toward the potential applications of EO in the fields of geography, agriculture, water resources, geology, and oceanography (NASA 2017; Haklay et al. 2018). The famous photograph of the rising Earth (Earthrise) taken from the lunar orbit in December 1968 by astronaut William Anders is considered the most influential environmental picture ever (Moran 2018). Astronauts have often expressed their experiences on looking at the Earth from space—a planet full of water and without borders—and how the sight made them feel small and vulnerable (Shrestha and Bajracharya 2011). Earth’s images from space have urged us to think of and understand our planet as a system. The launch of Landsat 1 in 1972 symbolized the beginning of the modern EO era and provided a consistent set of synoptic, high-resolution images (80 m) to the scientific community (Zhou and Kafatos 2002). Since then, EO has proven to be a powerful tool to generate information across the globe—information that is consistent, transparent, reliable, verifiable, and not restricted by national borders.

Our daily lifestyles have dramatically changed in today’s increasingly global, connected, and digital world, dictating how we spend our work and social life (O’Sullivan et al. 2018). EO data and services have become an integral part of modern society, ranging from monitoring global climate to navigating cars or exploring online detailed images of our neighborhood with our mobile phones. The

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evolution of citizen science and volunteered geographic information (VGI) has resulted in concrete projects like OpenStreetMap (Brovelli et al. 2020). We are now accustomed to accurate hourly weather forecasts and to following satellite images of swirling storms hitting coasts and cities. A combination of satellite data and weather models has made it possible to forecast discharge in each stream segment and also the extent of flood two weeks ahead, thereby helping in better preparedness to tackle any potential disaster (Souffront et al. 2019; Nelson et al. 2019).

The wide range of information collected by EO directly or indirectly supports all functions of government, economic sectors and in tracking biodiversity and wildlife trends; it also helps in measuring land-use change and deforestation; monitoring natural disasters such as fires, floods, and earthquakes; managing natural resources, such as energy, freshwater, and agriculture; addressing emerging diseases and health risks; and predicting and mitigating climate change (Anderson et al. 2017; Petiteville et al. 2015; Paganini et al. 2018).

Today, all countries are facing complex challenges of climate and environmental, sociocultural, and economic changes which are having an impact on natural environments and livelihoods. This calls for immediate actions, both globally and locally. So, realizing the need for unified interventions, all member states of the United Nations have adopted the 2030 Agenda for Sustainable Development, which provides a shared blueprint for peace and prosperity for the people and the planet (UN 2015). The agenda includes 17 Sustainable Development Goals (SDGs), which the countries need to address in a global partnership. These goals, targets, and indicators have been designed to measure, manage, and monitor progress in a uniform and systematic manner across the globe. EO has a significant role to play in this regard by bringing in spatial dimension to natural resources and socioeconomic statistics, while also allowing for disaggregation and granularity of the indicators (Paganini et al. 2018). EO data can support in analysis, modeling, and mapping SDGs which can then provide the integrative and quantitative framework necessary for global collaboration, consensus, and evidence-based decision-making (Liu et al. 2020). The global interest in EO is also demonstrated by the membership of more than 100 national governments and over 130 participating organizations in the Group on Earth Observations (GEO) which envisions “a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive, and sustained Earth observations” (<http://earthobservations.org>). Moreover, initiatives such as the United Nations Office for Outer Space Affairs (UNOOSA) for promoting international cooperation in the peaceful uses of outer space, and its United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) are examples of international efforts in the use of EO for societal benefits (<http://unoosa.org>). UN-SPIDER supports the developing countries to have access to specialized EO technologies which are essential in the management of disasters and reducing disaster risks. EO-based applications and services are increasingly being used for emergency response (Petiteville et al. 2015) and environmental monitoring, which are mainly seen as humanitarian needs. EO is also contributing to the emerging markets and providing opportunities for small and

medium enterprises, thereby being of value for citizens, government agencies, and the commercial industry (O'Sullivan et al. 2018).

It was the opening of the United States Geological Survey's Landsat archive in 2008 that greatly encouraged the development of applications using EO data. For the first time, a systematic, decades-long archive of our planet became freely available. The benefits to the US and international users from the Landsat imagery were estimated at \$3.4 billion in 2017 (Straub et al. 2019). This open-data policy resulted in a 60-fold increase in daily data downloads and crossed 100 million downloads as of March 2020 (Zhu et al. 2019; Straub et al. 2019; USGS 2020). Meanwhile, the Copernicus Program of the European Union implemented similar policies by providing free and open access to the vast majority of data and information delivered by the Copernicus Space infrastructure and the Copernicus Services (Zhu et al. 2019; Reillon 2017; Filchev et al. 2018). In the case of Asia, China, India, Japan, and South Korea are the major contributors in this area with their large suite of satellites; they have also initiated open-access policies on some selected data sets. Another development in the field of EO is the considerable increase in CubeSats which have changed the way satellites are built, launched, and used to address different needs (Thyrso et al. 2019). Besides, the adoption of these disruptive satellite technologies by private players like Planet has made any part of Earth accessible on a daily basis (<http://planet.com>).

The large volumes of free Landsat, Sentinel, and many other resources in the application ready data (ARD) format provided through cloud computing services with programming interfaces and powerful processing capabilities is seen as the democratization of satellite mapping (Dwyer et al. 2018). Efforts are also being made by space agencies on joint development and continuous innovation in the space sector; these are driven by national security and science objectives, user needs, and the pursuit of human space exploration (Zhu et al. 2019; ESRE Whitepaper 2017). Today, we observe a rapid transformation in the international space sector alongside the emergence of Space 4.0, which has been characterized by increased interaction among governments, the private sector, society, and the political community (Mazzucato and Robinson 2017). This is often seen in conjunction with the Fourth Industrial Revolution that has transformed the production cycle which is now being driven by digital technologies such as artificial intelligence (AI), machine learning (ML), cloud computing, Internet of things (IoT), and big data analytics (Filchev et al. 2018; Vaidya et al. 2018). Meanwhile, many developments from other areas, such as data cube technologies and block chain, are being adopted or explored for implementation in EO applications (ESA 2019; Sudmanns et al. 2019; O'Sullivan et al. 2018; Baumann et al. 2018). Then there is the factor of next-generation EO satellites which are expected to be highly intelligent and possessing the capability to integrate sensors, data-processing devices, and communication systems, thereby making it possible to carry out global surveys and real-time environmental analysis (Liu et al. 2020). With the maturity and convergence of these evolving technologies, we can expect unprecedented opportunities from EO to serve the needs of our communities, nations, and the world as a whole.

That said, despite these technological advances, there are many parts of the world where the communities and countries face enormous challenges driven by local and regional drivers of global climate change. The Hindu Kush Himalaya (HKH) in South Asia is one such region coping with immediate threats to its livelihoods, biodiversity, and ultimately, sustainability, due to human- and climate-induced changes. The HKH region covers parts or whole of Afghanistan, Pakistan, north-eastern and western Himalayas of India, the Tibetan plateau of China, Nepal, Bhutan, Bangladesh, and Myanmar. Also known as the third pole of the world and the “water towers” of Asia due to the vast reserves of freshwater on its mountains, it is the source of major Asian rivers and provides essential resources to around 1.9 billion people within and downstream of the region. Therefore, the environments and the natural resources of the HKH have both regional and global significance (Wester et al. 2019). Since 1983, the International Center for Integrated Mountain Development (ICIMOD), an intergovernmental organization based in Kathmandu, has been working in the areas of environmental conservation and protection of livelihoods in the HKH region (www.icimod.org).

As a knowledge and learning center, ICIMOD develops and shares research, information, and innovations in order to empower the people of the HKH region (ICIMOD 2018). Some of its priorities have been to bridge data gaps and avail of information technologies so as to promote evidence-based decisions at both local and national levels. In the case of applying and demonstrating EO and geospatial technologies in the region, ICIMOD has been working since the early 1990s by strengthening the capacity of national institutions to adapt to these new developments. Toward this end, specifically in 2010, ICIMOD became the host of the regional hub of a program called SERVIR. SERVIR is a partnership among the United States Agency for International Development (USAID), the National Aeronautics and Space Administration (NASA), and leading regional organizations. It develops innovative solutions to improve livelihoods and foster self-reliance in Asia, Africa, and the Americas. As a global program, SERVIR brings together a network of partners from NASA centers, research agencies, and other SERVIR regional hubs worldwide in order to work on the common problems that the countries are facing; it helps these countries adopt the latest methods and technologies, and designs appropriate services to address the problems. Empowering local institutions to use and adopt advanced technologies provides immense opportunities to tackle the complex socioecological problems in the challenging environment of the world’s highest mountain region.

We, as part of SERVIR, have developed this book in order to share our approaches and methods developed over time, which we believe will be useful to the broader community that focuses on user-centered EO and geospatial applications and services. In this book, we have documented our experiences of a decade of implementing the SERVIR-HKH program that promotes EO applications to address the development challenges faced by the communities of the HKH region.

1.2 The Geographic Context

The mountains of the HKH region have attracted humans since ancient times as a sacred place to fulfill their spiritual quest. Besides, the challenges posed by the remoteness and tough terrain of the HKH mountains have drawn the attention of explorers and adventurers from all over the world. The HKH is characterized by mountain ranges that include all the highest peaks above 8000 meters from sea level; they separate the Tibetan plateau from the southern plains of the Indian subcontinent. The region extends over 3500 km, encompassing Afghanistan in the west to Myanmar in the east (Fig. 1.1). Ten large Asian river systems originate from the region, which include the Amu Darya, Indus, Ganges, Brahmaputra, Irrawady, Salween, Mekong, Yangtze, Yellow River, and Tarim (www.icimod.org).

The high variability in its topography makes the HKH region highly heterogeneous with unique microclimates and ecological conditions. This has spawned rich cultures and high biodiversity—the region accounts for all or part of four global biodiversity hotspots. But the region, home to the youngest mountains in the world, is rather fragile; this fragility stems from weak geological conditions, steep topography, strong hydrodynamics with short and intense monsoonal rainfall, and excessive human intervention. The communities who have lived with and adapted to the tough mountain environments for centuries are now facing frequent and unpredictable calamities in the form of floods, landslides, wildfires, and extreme weather (ICIMOD 2018).

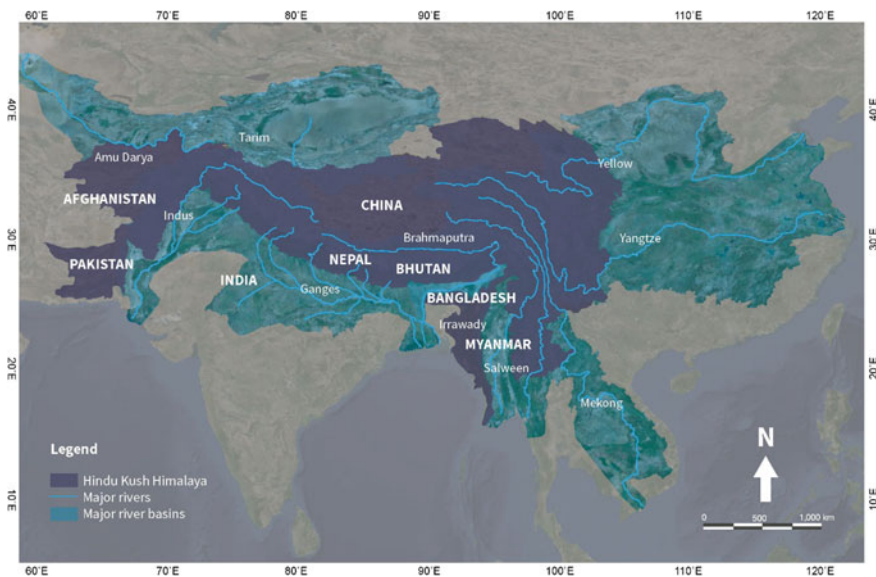


Fig. 1.1 Hindu Kush Himalaya region



Fig. 1.2 Farmlands in the high mountain district of Mustang, Nepal. Photo by Birendra Bajracharya

More recently, the HKH region has received growing attention as one of the most vulnerable ecosystems in the world; concerns have risen about rapid glacier melt and the consequent threats to water resources for both upstream and downstream communities (Wester et al. 2019). The visible impact of climate change on snow and glaciers, the water cycle, and biodiversity, as well as the increasing frequency and magnitude of climate-induced disasters is threatening the dynamics of life-support systems and the traditional adaptation and coping mechanisms of the local people (Bajracharya et al. 2007; Wester et al. 2019). The mountain communities still make their living from limited farmlands and natural resources (Fig. 1.2). However, recurring droughts are affecting agricultural production where access to water for farming was already under strain. The region is also facing multiple pressures from globalization by way of migration, unsustainable tourism, overexploitation of natural resources, and changes in land-cover and land-use practices (Wester et al. 2019).

1.3 Earth Observation Applications in the HKH

Understanding the complex natural and socioecological processes in the HKH has been challenging due to limited scientific data and information. Highly inaccessible terrains, harsh climatic conditions, and lack of investment in long-term scientific

research are major constraints for routine data collection, both in terms of spatial and temporal dimensions. In this context, to overcome the inherent complexities of such a mountainous region, satellite remote sensing offers the only means for consistent and synoptic observations of the HKH. EO, in combination with geospatial tools and models, paves way for better scientific understanding of the regional scenarios on climatic and environmental changes in these previously inaccessible areas (Thapa and Murayama 2012; Nelson et al. 2019; Sikder et al. 2019).

It is in this sphere of science and technology that ICIMOD has been playing a pivotal role. As an organization working on bridging the gaps between science, policies, and practices, ICIMOD understands the importance of knowledge generation and sharing so as to achieve sustainable and resilient mountain development. As an early adopter of scientific systems and technologies, ICIMOD established the Mountain Environment Regional Information System (MENRIS) division in 1990 to promote the use of geographic information systems (GIS) and remote sensing (RS) applications focusing on mountain environments. More recently, we have seen the synergistic convergence of geospatial technologies with mainstream information technology; there has been widespread penetration of smart applications into everyday lives—even in the HKH region. The evolution of EO applications in the HKH can be clearly understood through the journey of MENRIS over the past three decades, which is briefly illustrated below.

1.3.1 First Decade (1990–2000): Introduction of Geospatial Technology in the HKH

In the first decade, MENRIS activities could be broadly outlined in terms of capacity building and preparation of baseline geospatial data. In its early days, generating awareness about the technology among professionals, scientists, and decision makers was itself a major task. Realizing that qualified and capable human resources is fundamental to the meaningful utilization of GIS and EO, MENRIS started a series of comprehensive training programs. Key nodal agencies were identified in each HKH member country and they were assisted with hardware and software to establish GIS facilities; this was done under special arrangements with the United Nations Environment Program (UNEP) and the Environment Systems Research Institute (ESRI). The trainings were based on the PC ArcInfo software running in a desktop environment, which made it affordable to the national agencies. This model of combining training programs with the provision of software allowed the trainees to continue working with the system after completing the training. Setting up GIS labs and organizing regular trainings with universities and other key institutions helped in preparing the much-needed foundation for such a venture in the HKH region.

A major challenge was that base maps in the digital form were nonexistent for any work to begin on any real application. So, efforts were made on developing databases using the available paper maps. Digitizing all the 1 inch: 1 mile scale topographic maps of Nepal and making them freely available to the users was a massive undertaking. Also, a number of demonstration projects were implemented with partners. Some of the early examples of application of GIS and EO in the region are: MENRIS case study series on Dhading (ICIMOD 1992), Gorkha (Trapp 1995), and Lamjung (Trapp and Mool 1996); Kathmandu Valley GIS database (Shrestha and Pradhan 2000); GIS for municipal planning in Kirtipur (Shrestha et al. 2003); and land-cover mapping of Nepal and Pakistan using the National Oceanic and Atmospheric Administration's (NOAA's) Advanced Very High-Resolution Radiometer (AVHRR) data (UNEP 1998).

In 1996, the project “Strengthening of Training Capabilities for GIS Applications in Integrated Development in the Hindu Kush Himalayan Region,” funded by the Netherlands government, provided a further boost to develop structured capacity building activities with new courses on Infrastructure and Facility Planning; Mountain Agriculture and Land-use Planning; Monitoring, Assessment and Planning of Mountain Natural Resources; and Slope Stability Analysis and Hazard Mapping (Shrestha and Bajracharya 2002). These month-long trainings were organized in all member countries of ICIMOD. The technical trainings and policy workshops helped to generate the required skill sets among professionals from governments and relevant agencies, thereby raising awareness among the decision makers. During this time, the development of more user-friendly software interfaces on Windows, such as Esri's ArcView and Erdas Imagine, helped to improve the learning curve of the beginners and made it possible to include more advanced analytical tools in the trainings.

1.3.2 The Second Decade (2000–2010): Transition to Internet-Based Applications and Decision-Support Systems

MENRIS started its second decade by focusing on the emerging approaches in capacity building. A computer-based CD-ROM on “Applications of GIS and Remote Sensing to Sustainable Mountain Development” was developed—with concepts of geospatial technology, interactive and hands-on exercises, and supplementary materials—for the trainers to serve as a self-learning kit and as an aid in professional-level training programs. Internet map services were also introduced through ICIMOD's Mountain GeoPortal with interactive online training materials.

And from the years 2006–2009, advanced applications of EO on socioecosystem modeling were initiated through a Hindu Kush–Karakoram–Himalaya (HKKH) partnership project supported by the Italian Development Cooperation of the Ministry of Foreign Affairs. This partnership initiative took place under the umbrella of the global mountain partnership with the purpose of consolidating institutional

capacity for systemic planning and management of mountain resources at regional, national, and local levels. It focused on developing decision-support tools for conservation management in the three of the most elevated protected areas of the world: Everest National Park in Nepal; Chomolungma Nature Preserve in China; and Karakoram National Park in Pakistan (Bajracharya et al. 2010a). During this time, MENRIS adopted emerging and innovative approaches such as object-based classification for studying land-cover dynamics using high-resolution IKONOS imagery (Bajracharya et al. 2010b); integration of GIS visualization with system dynamics models on various socioeconomic drivers of change; and the implementation of web-based platforms for sharing data and applications. The second decade of MENRIS enabled the transition from desktop-based systems to server technologies on GIS/RS applications. In addition, MENRIS was also engaged in habitat suitability analyses in the eastern Himalayas, above-ground biomass estimation in the community forests of Nepal for Reducing Emissions from Deforestation and Forest Degradation (REDD), and in the preparation of glacier and glacial lake inventory of the entire HKH region (Chettri et al. 2010; Bajracharya and Shrestha 2011; Bajracharya et al. 2007). Over these two decades (1990–2010), ICIMOD, through MENRIS, had established itself as a regional resource center for providing innovative solutions which integrated GIS and remote sensing. ICIMOD also became a participating member of the GEO and worked with regional and international partners on fostering regional cooperation for improved access to and use of geo-based knowledge for the benefit and development of the mountain communities. Currently, ICIMOD is leading the Himalayan GEO, one of the task groups of the Asia Oceania GEO (AOGEO), with objectives to foster regional collaboration on EO applications and to link the priorities of the HKH region with global initiatives.

1.3.3 The Third Decade (2010–2020): Transformation from Applications to Services with SERVIR-HKH

While developing decision-support tools and researching similar work in other parts of the world, the MENRIS team came across the SERVIR-Mesoamerica website and noted that it had objectives which were very similar to MENRIS's. Subsequently, SERVIR and ICIMOD officials met at a GEO meeting in Athens in 2009 where the initial concept of SERVIR-Himalaya was discussed. (By this time, SERVIR had already established a new hub in East Africa in addition to its first hub—SERVIR-Mesoamerica, which was established in 2005.) Thus, by working on common objectives, ICIMOD became a SERVIR hub for the HKH region. The implementation of SERVIR in the HKH can be split into two phases.

SERVIR Phase 1 (2010–2015)

SERVIR-Himalaya formally started operations in July 2010 and was officially launched during the international symposium on “Benefiting from Earth Observation: Bridging the Data Gap for Adaptation to Climate Change in the Hindu

Kush Himalayan Region,” which was organized from October 4–6, 2010 in Kathmandu. Among those who attended the launch event were NASA Administrator Charlie Bolden, USAID Senior Deputy Assistant Administrator Michael Yates, GEO Secretariat Director Jose Achache, as well as senior government officials from the HKH countries and scientists from the region and beyond. The international symposium and the regional inception workshop set up a sound stage for SERVIR-Himalaya among the regional partners in ICIMOD member countries and clearly demonstrated SERVIR’s relevance in the region (Shrestha and Bajracharya 2011).

The scope of SERVIR-Himalaya was defined within four major areas of its results framework: capacity building of ICIMOD as the regional center for EO applications; building the capacities of national institutions in the region; promoting platforms for data sharing; and developing customized tools and products to support decision-making. While SERVIR-Himalaya was the third hub to join the SERVIR network, the ground realities differed greatly from those prevailing in the other two hubs in Mesoamerica and Africa. The countries of the HKH region had their own individual institutional setups, and the national capacities of these countries varied largely in terms of EO technologies. It was then realized that the essence of developing successful EO applications lay in focusing on the needs of the national institutions and the end users of the system.

A preliminary needs assessment was carried out to identify the key regional issues and the national priorities and capacities of the institutions of the HKH countries before initiating the design and development of information products and services (ICIMOD 2010). The assessment focused on a wide range of issues which were often interrelated, involving a large cross-section of institutions and people from different countries with different levels of capacity. Therefore, a qualitative approach was adopted with standard tools for the needs assessment—these are more intuitive than quantitative methods. As part of this effort, in order to analyze relevant recent and ongoing initiatives and to identify potential users and partners, several activities were carried out: literature reviews; consultation workshops; focus group meetings with the management and professionals; and questionnaire surveys in Bangladesh, Bhutan, China, India, Nepal, and Pakistan. The user landscape included government ministries and departments which were the mandated institutions and primary stakeholders, UN organizations and donors, universities, local governments, and non-governmental organizations. The needs assessment reinforced the fact that the information system and the databases in the region were weak and needed to be developed; and that remote sensing and modeling technologies were at a very early stage of development or even nonexistent. So, there was a need for the professionals to have hands-on experience in climate models with the capacity to capture complex terrain features and also a need to improve understanding about the regional and local dimensions of vulnerability.

A demand–supply model (Fig. 1.3) was then framed, looking into the demand for better information and supplying high-quality, user-tailored tools, and information services. A number of science applications were designed, using satellite data and predictive models, to develop the visualization tools that had been

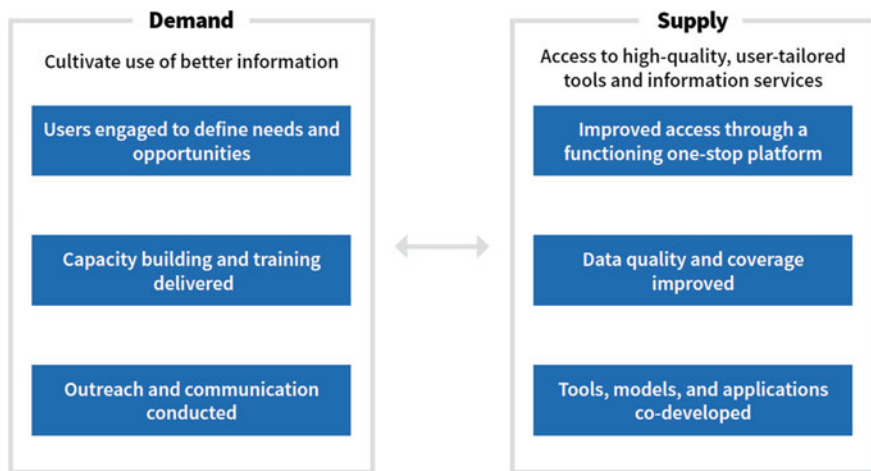


Fig. 1.3 Demand and supply model

prioritized based on the needs assessment; another aspect that was considered was the feasibility of availing data and technologies. The assessment had focused on the themes of cryosphere, ecosystems and biodiversity, disaster risk reduction, and transboundary air pollution (Table 1.1). Detailed assessments and implementation plans for each science application were then prepared by identifying user requirements, products, and methodologies. Each application was planned to be made accessible through web-enabled systems and also included user-friendly tools and functionalities.

In addition to the science applications being developed by the hub, there were three applied sciences projects which were implemented through NASA grants by a SERVIR applied sciences team; these projects also enabled US-based research organizations to complement the hub’s activities. The projects were: a study led by Arizona State University on glacier and alpine hazards in relation to development and habitation; a study led by the University of Washington on early warning, mapping, and post-disaster visualization of the water resources of low-lying deltas; and a study led by the R&D organization Battelle on the use of satellite products for air quality monitoring, analysis, and visualization.

In order to promote the involvement of national/local-level organizations in the applications of EO and geospatial technologies, two streams of a small grant program were also implemented. One set of eight grants was provided through an open call, while another six grants were provided through a selective call for proposals. These included applications that varied from flood forecasting, hazard mapping, and UAV for REDD, to the assessment of grazing intensity for rangeland management, engaging local citizens in agricultural mapping, and the dissemination of community-based forest-fire information. These applications were carried out by agencies in Bangladesh, Nepal, Pakistan, and India. All the small grant programs

Table 1.1 List of science applications in SERVIR-Himalaya (Phase 1)

Theme	Science application	Geographic coverage
Cryosphere and water	MODIS-based regional snow-cover area mapping and monitoring system	HKH region
	Run-off modeling using the CREST model in Bhutan under different climate change scenario	Bhutan
Ecosystem and biodiversity	Multiscale biomass assessment models and the REDD+ MRV process	Nepal
	Land-cover change and GHG inventories	Bhutan, Nepal
	Phobjika wetland habitat conservation studies	Bhutan
	Development of rangeland decision-support system in the HKH region of Pakistan	Pakistan
	Forest-change proneness modeling	Bhutan, Nepal, Bangladesh
Disaster management	Forest-fire detection and reporting system	Bhutan, Nepal
	Wireless sensor network for community-based flood early warning system	Bangladesh
Agriculture food security	Satellite-based crop monitoring and production assessment	Nepal
Air quality monitoring	Regional aerosol mapping using MODIS and AERONET station data	HKH region

had components of fieldwork and engagement with communities, which was enormously useful in catalyzing innovative ideas and bringing them to the local level.

Since the beginning of SERVIR-Himalaya, there has been a building up on past efforts and approaches of MENRIS in designing and organizing training programs. For example, the aspect of focusing on youth was strengthened through youth forums and through programs like NASA DEVELOP and My Community, Our Earth (MyCOE). All of these added new dimensions to the capacity building efforts.

SERVIR Phase 2 (2015–2020)

The start of the second phase of SERVIR in 2015 saw new arrangements in the hub's operations. First and foremost, at the beginning of the new phase, the hub was officially renamed as SERVIR-Hindu Kush Himalaya (SERVIR-HKH) and expanded to include a specific component on Afghanistan. In the first phase, the contract management of the USAID development funds for SERVIR at ICIMOD was conducted through an agreement with NASA; in the second phase, it was through USAID. In this new configuration, NASA optimized its role to focus on: science coordination and technical backstopping; connecting the hub in a better way with the scientific communities; facilitating connection with subject-matter experts; providing access to EO data and methods; and giving support on Geospatial Information Technology (GIT). In this phase, NASA continued to support and

expand its use of competitive grants through the SERVIR applied sciences team and worked toward better alignment of the selected projects to the needs of the hub. NASA grants are awarded to US-based organizations (academic, non-governmental, the private sector, and the government, besides NASA centers) through a competitive open call. In the second phase of SERVIR, USAID assumed the responsibilities of funding and procurement through its global development mandate and coordination with its regional and bilateral missions. Also, a global SERVIR support team (SST), managed by USAID, was formed to support the hub in functions such as communications, monitoring, evaluation, and learning (MEL), and to facilitate exchanges outside and across the network of SERVIR hubs (Fig. 1.4).

The experiences of the first phase showed that a supply-driven approach tended to limit its focus to the available technologies and data resources while designing applications. Although these applications are somewhat simpler to develop, their use was often short lived due to the limited consideration of the problems they were designed to address as well as by not giving enough attention to the people who were supposed to use them. In the second phase of SERVIR, a services approach was implemented and adopted as a holistic framework—it began with the “problem” for which a solution is needed and kept the user at the center of design, delivery, and implementation. This approach not only resulted in a better

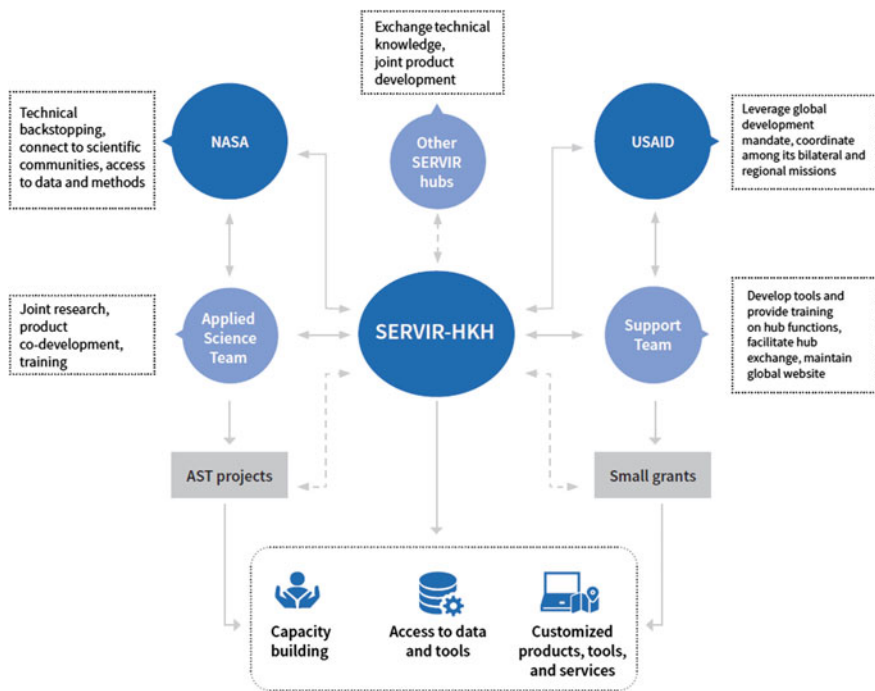


Fig. 1.4 SERVIR network

understanding of user needs but also enabled true co-development with the end users, ultimately leading toward long-term impact. As part of this effort, SERVIR-HKH contributed to the SERVIR Service Planning Toolkit which has become an invaluable resource to adopt the services approach in order to pave way for better design, delivery, and implementation of EO services for long-term impact.

To bring uniformity across the network of SERVIR hubs, four broad service areas were identified: agriculture and food security; land use, land cover, and ecosystems; water and hydro-climatic disasters; and weather and climate. With all the hubs adopting a common framework and working on the same priority service areas, the opportunities increased for cross-hub collaborations. The four SERVIR applied sciences team projects in the second phase also focused on: the implementation of a South Asia land data assimilation system; enhancement of stream-flow prediction; assessment of high-impact weather; and estimation of snow-water resources. The tools and methods provided by these projects were closely integrated with the development of services on agricultural drought, flood early warning systems, and extreme weather forecasts (Table 1.2).

Since the applications of EO are heavily dependent on technology, SERVIR-HKH recognized that ensuring adequate GIT infrastructure and human resources are equally important to create enabling environments at the hubs and with implementing partners. Dissemination platforms for delivering appropriate and timely information to the users are a critical component of SERVIR-HKH. Depending upon the nature of the service, SERVIR-HKH has developed information systems that vary from simple query and visualization applications to advanced, fully automated systems which allow users to visualize data and information in various formats such as dynamic maps, charts, tables, and infographics. In addition, a number of mobile-based field-data collection tools have been developed, taking advantage of the growing use of smartphones in the region. The

Table 1.2 List of SERVIR applied sciences team projects in Phase 2

S. No.	Project description	Area covered	Leading institution
1	Comprehensive stream-flow prediction and visualization to support integrated water management	HKH/ Bangladesh, Nepal	Brigham Young University
2	Monitoring intense thunderstorms in the HKH region	Bangladesh, Bhutan, Nepal	NASA-Marshall Space Flight Center
3	Seasonal prediction of HKH hydrological extremes with the help of the South Asia land data assimilation system	HKH	John Hopkins University
4	Managing the changing nature of water resources south of the Himalayas	HKH	NASA-Jet Propulsion Laboratory

core principle of free and open access to data is central to SERVIR's approach in generation of information and providing access to all of its information services.

Another major effort of SERVIR-HKH has been to fill the capacity gaps among individuals and institutions in the use of EO information products and systems for evidence-based decision-making. As part of this effort, SERVIR-HKH developed a capacity building strategy to address the needs at various levels and to ensure sustained institutional capacities at national and local levels. Trainings related to the science and technologies adopted in the different services developed by SERVIR-HKH are given priority while keeping abreast with emerging technologies such as cloud computing, Synthetic Aperture Radar (SAR), and machine learning. Special trainings are designed to target young women and high-schoolteachers in order to increase awareness and interest among women professional to adopt careers in GIT, as well as to reach out to the local communities through schoolchildren.

SERVIR's adoption of the service approach has also put extra emphasis on gender, user engagement, and communications. SERVIR-HKH recognizes the need to consider gender impacts beyond just the use of a wide range of technologies. Thus, efforts are made to explore connections between gender and GIT, by including gender-related information to improve decisions involving the issues of the most vulnerable and marginalized groups in society. SERVIR-HKH has also developed a gender strategy and action plan to improve upon the methods of collecting gender-disaggregated data; the plan also seeks to customize information services to address gender needs; besides, it aims to promote GIT careers and women's participation in capacity building. The area of service planning also entails a knowledge management and communication strategy for targeted communication, sharing, and dissemination of the knowledge generated by SERVIR-HKH; this is to foster use by the target audiences and ultimately trigger behavioral change. Such knowledge shared and delivered to the users in appropriate formats, through relevant channels at appropriate timings, is central toward enabling any stakeholder to take informed decisions.

User engagement in the context of SERVIR-HKH is a multifaceted, multi-stakeholder, and multi-country complex phenomenon with both challenges and opportunities. SERVIR-HKH's user-engagement strategy ensures the systematic involvement of users at different stages either as co-creators, co-designers, co-implementers or as potential beneficiaries. Starting with the assessment of the user landscape and stakeholder mapping, the users are then engaged in various consultations and training events. Formal mechanisms such as a memorandum of understanding (MOU), a letter of agreement (LOA), and a letter of intent (LOI) are brought to bear for long-term collaborations with key institutions. These instruments are enormously valuable for institutional continuity should key personnel leave, be transferred, or if there is a change in government in the countries where SERVIR-HKH works.

Ultimately, all the efforts being made by SERVIR at the global level and in the regions are driven by the goal to create lasting impacts on the lives and livelihoods of the communities through the best use of the available EO and GIT resources. We

strive to achieve our goals by defining theories of change and by identifying impact pathways. We believe that an MEL framework will guide us through the pathway and expedite learning and the adoption of new knowledge as we move along in our journey to connect “Space to Village”—the mantra of SERVIR.

The diversity of socioeconomic and political contexts, the complex user landscape, and the various types of services that have been developed have provided enormous learning opportunities to us during the design and implementation of the services. This book is an outcome of our learnings during the evolution of approaches and processes from phase one to phase two where we managed the priorities of users and professionals and aligned with the technological advances in the global market.

1.4 Overview of the Book

This book consists of nineteen chapters including this chapter. In this book, we refer to the HKH hub at ICIMOD as SERVIR-HKH, while SERVIR represents the global network including all the hubs. Chapter 2 explains the services approach and the SERVIR Service Planning Toolkit. It describes the major components of the toolkit and provides an example of its implementation in one of our services. Chapter 3 explains our efforts in understanding the gaps, needs, and priorities of national agencies in using EO and GIT for decision-making. Here, we present a study and its findings to understand the mandates of the key agencies and the status of their capacity and resources to develop and use geospatial tools. The study methodology includes literature review, institutional surveys, and key informant interviews, which resulted in findings related to different aspects of EO applications, ranging from current research and knowledge generation to human resources and the IT environment, as well as data-sharing policies at national and agency levels.

Adopting agriculture and food security as a priority service area is justified by the fact that the HKH region is predominantly an agrarian society with the majority of the population depending on agriculture for their livelihoods. The agricultural practices in the region largely depend on monsoonal rain which has been experiencing increased anomalies due to changes in climate. A wealth of climate and EO information is available from the past few decades which has been helpful in monitoring, modeling, and understanding the climatic variables—this can help in decision-making and agricultural planning. Chapter 4 presents our services on drought monitoring and in the establishment of an early warning system for the same that not only supports national- and local-level planning, but also provides agro-advisory services for preparedness to mitigate the impacts of drought on agriculture. In this regard, regional and national drought monitoring and outlook systems have been developed, which covers Afghanistan, Bangladesh, Nepal, and Pakistan. Chapter 5 focuses on another important area of EO applications in agriculture—the assessment of in-season crop area; this is critically important for national food security strategies. For example, SERVIR-HKH initiated a wheat-mapping activity in Afghanistan in response to a

high-level request from its Ministry of Agriculture, Irrigation, and Livestock (MAIL). Then, an operational system for in-season monitoring of wheat crop was developed, utilizing optical (Sentinel-2) and Synthetic Aperture Radar (SAR, Sentinel-1) data, and by integrating decision trees and a machine learning algorithm in the Google Earth Engine cloud platform. In this chapter, we present the methodologies, the findings, and the institutional challenges that had to be tackled during the implementation of this system.

Chapter 6 presents the Regional Land-Cover Monitoring System (RLCMS) and the national systems which are implemented in Afghanistan, Bangladesh, Nepal, and Myanmar. The availability of free online satellite data and advances in cloud computing platforms such as Google Earth Engine made it possible to develop RLCMS and adopt it for generating more frequent land-cover maps at regional and national scales. The methodology was initially developed by SERVIR-Mekong and then was adopted for the HKH region through a multi-hub, co-development process. Chapter 7 presents another service that provides scientific data and information on the vulnerability of forest ecosystems to climate change and anthropogenic drivers; this service involves the use of ecological modeling techniques to support the identification and implementation of adaptation and forest-management strategies. One of the important drivers of forest degradation is forest fire, which has adverse ecological and economic effects. A reliable and timely fire detection and monitoring system is an important component of forest-fire management. Chapter 8 presents the forest-fire monitoring system developed by SERVIR-HKH. The innovative system identifies forest fires through the hotspot data generated by the Moderate Resolution Imaging Spectroradiometer (MODIS), and uses forest masks and overlays of administrative units. It sends SMS and email alerts to the corresponding authorities in the event of fire incidents in their area, as well as to the relevant national department. The forest-fire monitoring system has been useful in enhancing understanding about the spatial and temporal patterns of fire incidents and in identifying the vulnerable areas. The system also includes a function to report fire incidents from the field, thus making it a two-way process whereby data can be captured from both space and at the community level.

The HKH region is a hotspot of predominantly natural hazards, with frequent floods and extreme weather events playing havoc with people's lives and livelihoods. The services on water and hydro-climatic disasters include enhancing the flood early warning system, rapid flood mapping using multi-temporal SAR images, and mapping and change assessment of glaciers and glacial lakes. Chapter 9 presents our work on enhanced flood early warning, which is based on the novel stream-flow prediction tool that increases flood-forecast lead times in Bangladesh, Bhutan, and Nepal. This includes an operational 15-day flood forecast that integrates local data into a global model using methods co-developed by applied science team and local experts. Longer lead times and access to accurate and appropriate information ensure better preparedness for disaster responders, who can then help save lives and property. While early warnings can reduce the impacts of flood on lives and properties, timely and rapid flood inundation mapping plays an important role in rescue and relief operations, as well as in post-flood damage

assessment. Chapter 10 presents our work on an operational methodology for rapid flood inundation mapping which helps in assessing flood situations. Since the monsoon period is always cloudy, we use Sentinel-1 SAR images during this period to prepare maps of the inundated areas. These areas are overlaid with pre-flood land-cover maps in order to identify settlements and agricultural areas, and the maps are distributed to the different agencies working on flood response and relief. In Chap. 11, we present our work on mapping glaciers and glacial lakes in Afghanistan. In response to a request from the Ministry of Energy and Water in Afghanistan, SERVIR-HKH carried out a study of glacier and glacial lake dynamics from 1990–2015 for the entire country. Glaciers are key freshwater resources and play a significant role in local and regional hydrology; they also carry with them the threat of glacial hazard. The glacier and glacial lake database were prepared by applying the semiautomatic object-based image classification method using Landsat imagery from the years 1990, 2000, 2010, and 2015; in this exercise, each glacier was mapped. In the 25-year period, the study not only showed a significant decrease in the number of glaciers but also recorded how the formation and expansion of glacial lakes have been adversely affected. Under the service area of weather and climate, a High-Impact Weather Assessment Toolkit (HIWAT) was developed to facilitate probabilistic forecasting and to assess the hazards associated with high-impact weather. Presented in Chap. 12, HIWAT consists of a real-time, convection-permitting ensemble numerical weather prediction system based on the Weather Research and Forecasting (WRF) model and a situational awareness tool that gauges thunderstorm intensity through satellite measurements. The forecast is disseminated to the stakeholders via an innovative data visualization platform. The precipitation registered in the forecast is also used in a routing model to predict flash floods in smaller watersheds.

Enabling environments that support the various services are very important where these enablers ensure that the services are efficiently deployed and also used by the target audience in an effective manner. Chapter 13 introduces the various information systems and mobile data collection tools developed by SERVIR-HKH. It provides details on the overall application development process and on the various types of technologies that are in use. Chapter 14 presents the capacity building strategy adopted by SERVIR-HKH and its implementation for strengthening the capacities of government organizations, development stakeholders, and individuals on the use of EO and GIT applications. Overall, it covers capacity gaps and identifies needs; it also dwells on facets such as structured planning, implementation, monitoring, evaluation, and successive learnings. It illustrates the four categories of training processes—standard training, training of trainers, on-the-job training, and exposure learning—that were strategically carried out by SERVIR-HKH with a focus on priority service areas. Chapter 15 describes our efforts in integrating the aspect of gender into service planning and design, and how the participation of women was promoted through various initiatives. As the prevalent inequality between women and men is bound to influence the development of technologies, this chapter tracks the connection between gender and technology over the decades and discusses how SERVIR-HKH integrates gender concerns into its program and activities.

Next, in Chap. 16, we deliberate over the importance of communications in providing the right type of data at the right time and in translating data visualizations into decisions. As we all know, communication plays a crucial role in making science available and accessible to the people. Since its inception, SERVIR-HKH has adopted an integrated approach toward communication processes; it has facilitated internal knowledge sharing and network-wide communications, as well as fostered brand recognition and trust among partners; dissemination and outreach too have played key roles. In place was also a communication strategy that guided the knowledge management and knowledge-sharing processes; various online and offline tools too were in use to help SERVIR-HKH achieve its strategic goals. Chapter 17 presents the key learnings while strengthening engagement with the users. This chapter highlights the impact of embedding the user-engagement approach, more particularly emphasizing that if the users are given ownership, there is a greater chance that products and services will be used effectively. In Chap. 18, we share our experiences on how the MEL practice enhanced result orientation, adaptive management, mutual understanding, and ownership by the stakeholders. This ultimately leads to better user-tailored EO products and services, and ensures the adoption and use of EO and GIT in evidence-based decision-making for the benefit of the vulnerable communities. We explain our learnings systematically with evidences and examples from the region.

Finally, the Chap. 19 has its spotlight on the lessons, challenges, and opportunities in the use of EO and GIT applications and services via SERVIR-HKH. Over the years, there have been significant developments in the field of EO and GIT while the capacity of the key agencies to leverage these advancements to produce, disseminate, and use the information has been rather limited. However, there are many opportunities in the region to fill the existing gaps in data, capacity, and services while simultaneously there is an increasing acceptability of EO and GIT as a means to improve the decision-making process in national institutions. It is observed that the partners' confidence has been growing on the use of SERVIR-HKH applications and services, and that enormous progress has been made on all fronts. The SERVIR network and its partnership with many institutions throughout the world provide excellent opportunities to usher in the latest advancements in science and technology and create broader perspectives in addressing the problems plaguing the HKH region.

References

- Anderson K, Ryan B, Sonntag A, Kavvada A, Friedl L (2017) Earth observation in service of the 2030 agenda for sustainable development. *Geo-Spat Inf Sci*. <https://doi.org/10.1080/10095020.2017.1333230>
- Bajracharya SR, Shrestha B (2011) The status of glaciers in the Hindu Kush-Himalayan region. ICIMOD, Kathmandu

- Bajracharya SR, Mool PK, Shrestha BR (2007) Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan. ICIMOD, Kathmandu
- Bajracharya B, Pradhan S, Shrestha B, Salerno F (2010) An integrated decision support toolbox for the management of mountain protected areas. *Mt Res Dev* 30(2)
- Bajracharya B, Uddin K, Shrestha B, Chettri N (2010) Understanding land cover change using a harmonized classification system in the Himalayas: a case study from Sagarmatha National Park, Nepal. *Mt Res Dev* 30(2)
- Baumann P, Rossi AP, Bell B, Clements O, Evans B, Hoinig H, Hogan P, Kakalettris G, Koltsida P, Mantovani S, Figuera RM, Merticariu V, Dimitar Misev D, Pham HB, Stephan Siemen S, Wagemann J (2018) Fostering cross-disciplinary earth science through datacube analytics. In: Mathieu PP, Aubrecht C (eds) *Earth observation open science and innovation, ISSI scientific report series 15*. Springer Open. https://doi.org/10.1007/978-3-319-65633-5_1, https://link.springer.com/chapter/10.1007%2F978-3-319-65633-5_5
- Brovelli MA, Ponti M, Schade S, Solís P (2020) Citizen science in support of digital earth. In: Guo H, Goodchild MF, Annoni A (eds) *Manual of digital earth*. SpringerOpen
- Chettri N, Sharma E, Shakya B, Thapa R, Bajracharya B, Uddin K, Oli, KP, Choudhury D (2010) Biodiversity in the Eastern Himalayas: Status, trends and vulnerability to climate change; Climate change impact and vulnerability in the Eastern Himalayas. Technical report 2, ICIMOD. ISBN: 978-92-9115-147-9
- Dwyer JL, Roy DP, Sauer B, Jenkerson CB, Zhang HK, Lymburner L (2018) Analysis ready data: enabling analysis of the landsat archive. *Remote Sens* 10:1363
- ESA (2019) Blockchain and earth observation. White Paper
- ESRE Whitepaper (2017) Selected trends and space technologies expected to shape the next decade. The association of european space research establishments
- Filchev L, Pashova L, Kolev V, Frye S (2018) Challenges and solutions for utilizing earth observations in the “Big Data” era. In: BigSkyEarth conference: AstroGeoInformatics, Tenerife, Spain, 17–19 Dec, 2018
- Haklay M, Mazumdar S, Wardlaw J (2018) Citizen science for observing and understanding the earth. In: Mathieu PP, Aubrecht C (eds) *Earth observation open science and innovation, ISSI scientific report series 15*. https://doi.org/10.1007/978-3-319-65633-5_5
- ICIMOD (1992) Applications of GIS for natural resource management in Dhading district, Nepal. ICIMOD
- ICIMOD (2010) SERVIR Himalaya preliminary needs assessment. ICIMOD
- ICIMOD (2018) Strategy and results framework 2017. ICIMOD
- Liu Z, Foresman T, van Genderen J, Wang L (2020) Understanding digital earth. In: Guo H, Goodchild MF, Annoni A (eds) *Manual of digital earth*. SpringerOpen
- Mazzucato M, Robinson D (2017) Market creation and the European space agency (European Space Agency (ESA) Report)
- Moran J (2018) Earthrise: the story behind our planet’s most famous photo. *The Guardian*. <https://www.theguardian.com/artanddesign/2018/dec/22/behold-blue-plant-photograph-earthrise>
- NASA (2017) Sputnik and the dawn of the space age. <https://history.nasa.gov/sputnik/>
- Nelson EJ, Pulla ST, Matin MA, Shakya K, Jones NL, Ames DP, Ellenburg WL, Markert KN, David CH, Zaitchik BF, Gatlin P, Hales R (2019) Enabling stakeholder decision-making with earth observation and modeling data across the SERVIR hubs using Tethys platform. *Front Environ Sci: Freshwater Sci*. <https://doi.org/10.3389/fenvs.2019.00148>, <https://doi.org/10.1016/j.envsoft.2019.05.001>
- O’Sullivan C, Wise N, Mathieu PP (2018) The changing landscape of geospatial information markets. In: Mathieu PP, Aubrecht C (eds) *Earth observation open science and innovation, ISSI scientific report series 15*. Springer Open. https://doi.org/10.1007/978-3-319-65633-5_1
- Paganini M, Petiteville I, Ward S, Dyke G, Steventon M, Harry J, Kerblat F (2018) Satellite earth observations in support of the sustainable development goals, Special 2018 edition, ESA

- Petiteville I, Ward S, Dyke G, Steventon M, Harry J (eds) (2015) Satellite earth observations in support of disaster risk reduction, Special 2015 WCDRR edition. In: CEOS earth observation handbook for WCDRR, ESA
- Reillon V (2017) Securing the copernicus programme—why EU earth observation matters, EPRS, PE 599.407. <https://www.copernicus.eu/en/documentation/copernicus-policy/copernicus-policy>
- Shrestha B, Bajracharya B (eds) (2011) Proceedings of the international symposium—benefiting from earth observation bridging the data gap for adaptation to climate change in the Hindu Kush-Himalayas, 4–6 Oct 2010, Kathmandu, Nepal. ICIMOD
- Shrestha B, Pradhan S (2000) Kathmandu valley GIS database: bridging the data gap. ICIMOD
- Shrestha B, Bajracharya B (2002) GIS education—experiences from the Hindu Kush-Himalayan (HKH) region. Proceedings of ACRS 2002. <https://a-a-r-s.org/proceeding/ACRS2002/Papers/ED02-7.pdf>
- Shrestha B, Bajracharya B, Pradhan S, Rajbhandari L (2003) GIS for municipal planning: a case study from Kirtipur municipality. ICIMOD
- Sikder MS, David CH, Allen GH, Qiao X, Nelson EJ, Matin MA (2019) Evaluation of available global runoff datasets through a river model in support of transboundary water management in South and Southeast Asia. *Front Environ Sci*. <https://doi.org/10.3389/fenvs.2019.00171>
- Souffront MA, Nelson EJ, Shakya K, Edwards C, Roberts W, Krewson C, Ames DP, Jones NL (2019) Hydrologic modeling as a service (HMaaS): A new approach to address hydroinformatic challenges in developing countries. *Front Environ Sci: Freshwater Sci* (Oct 2019). <https://doi.org/10.3389/fenvs.2019.00158>
- Straub CL, Koontz SR, Loomis JB (2019) Economic valuation of landsat imagery, open-file report 2019–1112. US Department of the Interior, USGS
- Sudmanns M, Dirk Tiede D, Stefan Lang S, Helena Bergstedt H, Georg Trost G, Hannah Augustin H, Andrea Baraldi A, Thomas Blaschke T (2019) Big earth data: disruptive changes in earth observation data management and analysis? *Int J Dig Earth*. <https://doi.org/10.1080/17538947.2019.1585976>
- Thapa RB, Murayama Y (2012) Scenario based urban growth allocation in Kathmandu valley, Nepal. *Landscape Urban Plann* 105:140–148
- Thyrso V, Costa CA, Brandão AM, Bueno FT, Leonardi R (2019) Towards the Thousandth CubeSat: a statistical overview. *Int J Aerosp Eng* 2019(5063145). Hindawi. <https://doi.org/10.1155/2019/5063145>
- Trapp H (1995) Application of GIS for planning agricultural development in Gorkha district. ICIMOD
- Trapp H, Mool PK (1996) Lamjung district information system for local planning and assessment of natural resources using GIS and RS technology. MENRIS case study no. 4. ICIMOD
- UN (2015) Transforming our world: the 2030 agenda for Sustainable development, A/RES/70/1. <https://sustainabledevelopment.un.org/>
- UNEP (1998) Land cover assessment and monitoring pakistan, environment assessment. Technical reports, Vol 10-A. ICIMOD and UNEP
- USGS (2020) Landsat project statistics. <https://www.usgs.gov/land-resources/nli/landsat/landsat-project-statistics>
- Vaidya S, Ambad P, Bhosle S (2018) Industry 4.0—a glimpse. In: 2nd International conference on materials manufacturing and design engineering. Science Direct, Elsevier
- Wester P, Mishra A, Mukherji A, Shrestha AB (eds) (2019) The Hindu Kush Himalaya assessment—mountains, climate change, sustainability and people. Springer Nature Switzerland AG, Cham
- Zhou G, Kafatos M (2002) Future intelligent earth observing satellites. In: Pecora 15/land satellite information IV/ISPRS commission I/FIEOS 2002 conference proceedings
- Zhu Z, Wulder MA, Roy DP, Woodcock CE, Hansen MC, Radeloff VC, Healey SP, Schaah C, Hostert P, Strobl P, Pekel JF, Lymburner L, Pahlevan N, Scambos TA (2019) Benefits of the free and open landsat data policy. *Remote Sens Environ* 224(April 2019):382–385

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