Reform Earth Observation Science and Applications to Transform Hindu Kush Himalayan Livelihoods—Services-Based Vision 2030

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Abstract The Hindu Kush Himalayas (HKH) region with 210 million people living in the region poses significant scientific and technological challenges for livelihood improvement due to subsistence economy, livelihood insecurity, poverty, and climate change. The inaccessibility and complex mountain environmental settings carved special niche for Earth Observation (EO) science and significant contributions were made in the food security and disaster risk reduction sectors. The differentiated capacities of users to develop and use EO capabilities, challenges in outreaching the EO products to last mile users call for innovative ways of packaging EO products into actionable knowledge and services. This calls for great degree of reformation on EO community to tailor-made region specific EO sensors and models, mechanisms of synergizing EO knowledge with local traditional systems in addressing multiscale, and integrated end-to-end solutions. The paper addresses prospects and challenges of 2015–2030 to achieve success in three critical livelihood support themes viz food security, floods, and forest-based carbon mitigation. Different improvements in EO sensor and models to extend less than a day, all-weather imaging, improved hydro-meteorological forecasts, vegetation stress, and community carbon monitoring models are identified as priority areas of improvement. We envisage and propose mechanisms on how these EO advances could amalgamate into Essential HKH Variables (EHVs) on the lines of global Essential Climate Variables (ECVs) to provide turnkey-based actionable knowledge

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F. Hossain (ed.), *Earth Science Satellite Applications*,
Springer Remote Sensing/Photogrammetry, DOI 10.1007/978-3-319-33438-7_2

and services through global and regional cooperation. The complex web of users and orienting them toward adoption of EO services through multi-tier awareness, expertise development, policy advocacy, and institutionalization is also discussed. The paper concludes that the EO community needs to reform significantly in blending their science and applications with user-driven, need-based domains to provide better societal services and HKH livelihood transformation.

1 Introduction

The Hindu Kush Himalayan (HKH) region extends 3,500 km over all or part of eight countries from Afghanistan in the west to Myanmar in the east (Fig. 1). It is the source of 10 large Asian river systems and provides water, ecosystem services, and the basis for livelihoods to a population of around 210.53 million people in the region. The basins of these rivers provide water to 1.3 billion people, a fifth of the world's population. The human poverty, livelihood insecurity, food insecurity, gender, and social inequity continue to be the major detriments of livelihood quality across the region. The subsistence livelihood practices, globalization, liberalization, climate change, and vulnerability to disasters compounded with fragility, marginality, and inaccessibility are conceived as the critical factors regulating HKH region. Due to the very nature of mountain specificity, climate change is reported to largely govern the developmental trends of transitions from subsistence systems to commercial systems, increasing efficiency and productivity, high-value, niche-based and nonfarm products, and increased mobility–migration and remittances (Rasul 2014).

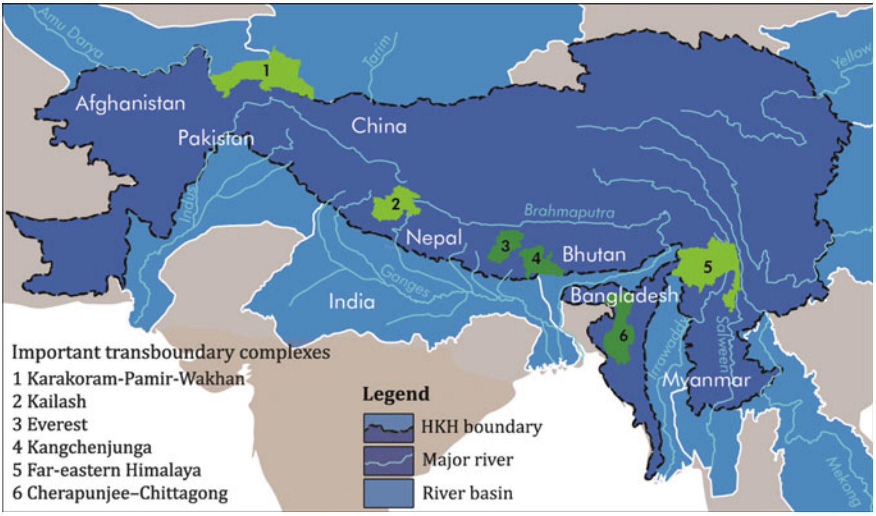

Fig. 1 The Hindu Kush Himalayan (HKH) region

The mean annual increase in temperatures by 2–3 °C are reported to have greater impacts on people and ecosystems of the HKH region (Anderson and Bows 2008; Hansen et al. 2013; Solomon et al. 2009). The high-resolution cryospheric–hydrological model projections have estimated increase in runoff levels due to increased precipitation in the upper Ganges, Brahmaputra, Salween, and Mekong basins, and from accelerated melt in the upper Indus (Lutz et al. 2014). The glaciers in the Himalaya are reported to be retreating faster than those in the Hindu Kush and Karakorum, with losses over 30 years of 5–55 % of area (Bajracharya et al. 2015). The impact of rising temperatures and loss of ice and snow in the region are affecting, for example, water availability (amounts, seasonality).

The ecosystem boundary shifts (tree line movements, high-elevation ecosystem changes), altered carbon fluxes, biodiversity change (endemic species loss, changes in predator–prey relations), and global feedbacks (monsoonal shifts, loss of soil carbon) are a few critical ecosystem impacts reported over HKH region due to climate change (Bates et al. 2008; Burkett et al. 2005; Holtmeier and Broll 2005; Parmesan 2006; Wang et al. 2000). The changes in rangeland calendars, rangeland degradation, and productivity losses across the entire HKH region due to unsustainable grazing practices and climate change are reported. The fragile mountain agriculture practices coupled with climate change impacts in terms of recurring droughts and floods have made mountain agriculture systems highly vulnerable to change and unsustainable production (Abbas et al. 2014; Sigdel and Ikeda 2010). The disaster frequency and associated societal and economic impact has increased by several folds (Etkin 1999; Kim and Marcouiller 2015).

While scientific data and information on the Himalayas are crucial to understand ongoing climatic and socioeconomic change processes in order to support policy planning and informed decision-making, the Himalayan region has a major data gap due to highly inaccessible terrain, inadequacy of resources and technologies, harsh climatic conditions, and lack of investments in long-term scientific research. Earth Observation (EO)-derived information bears special significance in the mountain areas, as it helps to access remote regions and to gain insights of regional scenarios, especially the climatic and broader environmental changes. The EO products today serve as major inputs to policy, planning and targeted interventions, contributing to building social capitals, natural resources assets, and environmental gains on the long-term basis (Jayaraman 2009).

The geospatial services help through cost and time savings, new/improved services, value of information, and extending strategic edge for planning. The in season crop production forecasts, disaster emergency and risk reduction, improved natural resources planning and nature conservation, building physical and social infrastructure, and natural resources assets are a few demonstrated examples, where geospatial systems contributed to effective economy and livelihood improvements. Sankar (2002) estimated that the value of Indian remote sensing products by providing value-added information and optimizing costs of conventional field surveys is around USD 427M. EO systems have contributed to disaster emergency planning and risk reduction processes, leading to avoided loss of life and property (Miller et al. 2011; Blaikie et al. 2014; Brown and Woolridge 2015).

Across the HKH region, there are good number of success stories in taking advantage of the science and observations afforded by satellites to make societal impacts and benefits (Gupta et al. 2015; Pilon and Asefa 2011). There are differentiated capacities among the HKH regional member countries with regard to the utilization of EO and geospatial technologies. The combined observational power of the multiple Earth observing satellites is currently not being harnessed holistically to produce more durable societal benefits. A fundamental challenge for the coming decade is to ensure that established societal needs help and guide scientific priorities more effectively, and that emerging scientific knowledge is actively applied to obtain societal benefits. New observations, analyses, better interpretive understanding, enhanced predictive models, broadened community participation, and improved means for information dissemination are all needed. Achieving these benefits further requires the observation and science program to be closely linked to decision support structures that translate knowledge into practical information matched to and cognizant of society's needs.

It is in this context, the present chapter reviews the current scenario and developments made during 2010–2015, and discusses prospects and challenges during 2015–2030 in evolving toward user-oriented EO applications for improving HKH livelihoods. Our analysis and suggestions are focused to address four essential elements: (1) new advances required in EO sensors to address increasing needs and challenges of natural resources and disaster sectors; (2) customization and new package of EO systems required to understand geophysical and biophysical complexities of mountain systems; (3) research and value-added systems to be improvised to move toward a *service provision* mode addressing societal benefits; and (4) gaps, challenges, and practices to be addressed for the better integration of stakeholder communities to achieve meaningful utilization of services. The data and information from the published literature, proceedings of stakeholder consultation meetings, current availability of datasets and infrastructure, and scenario of capacity building in the region formed the basis for our study. We present our analysis in three sections: (1) current scenario assessment, (2) prospects and challenges for the period 2015–2030 and (3) conclusions and recommendations. The study focused on three major livelihood critical areas viz food security, forest-based carbon mitigation and floods.

2 Current Scenario Assessment (2010–2015)

The current scenario assessment has drawn the findings and recommendations of needs and status assessment studies from SERVIR-Himalaya program. SERVIR (an acronym meaning "to serve" in Spanish) was initiated during 2005 as a joint venture between NASA and the U.S. Agency for International Development (USAID), to provide satellite-based EO data and science applications to help developing nations in Central America, Eastern and Southern Africa (in 2008), and the Hindu Kush Himalayas (in 2010) to improve their environmental decision-making. The requirements of the local and national institutions and diverse end users have been conceived as the basis for developing geospatial science applications. The key regional issues, national priorities, and capacities of the institutions of the regional member countries were assessed before initiating the design and development of information products and services within the SERVIR-Himalaya framework. A literature review was also carried out to analyze the existing documents, workshops, and study reports dealing with the issues of the HKH and the use of geospatial technologies to understand the past and ongoing initiatives, and identification of suitable institutions and people to participate in the needs and capacity assessment process.

For a more comprehensive need assessment and identification of priority applications, country-level stakeholder workshops were held consisting of focused group discussions and questionnaire under the themes of cryosphere, ecosystems and biodiversity, disaster risk reduction, and transboundary air pollution. An assessment of decision support tools and geospatial portals were also done in view of potential SERVIR products development. For each of these themes, SERVIR-Himalaya program assessed of major issues, identified and engaged key stakeholders in the countries, maintained awareness of ongoing initiatives, and synthesized gaps and opportunities. Further, a regional inception workshop was organized for more focused discussion on regional-level needs of SERVIR-Himalaya consisting of experts and professionals from all the eight countries of the HKH including the representatives from USAID and NASA.

The generic framework on current scenario assessment and user integration in application development was done in two phases: (1) product design, testing, and development (2) operational product delivery systems. The Phase-1 has essentially guided the strategic application development based on user diversity, needs, current ground support systems, technology potential facilitating the product design, testing, and development. The second phase addressed the ground operational segment, user diversity, and application use. Accordingly three critical application areas viz, Geo-societal applications using EO data for food security and disasters, assessment and monitoring support for climate change mitigation and adaptations, enabling systems/platforms for multithematic data and products organization, analysis, and dissemination.

Based on the information and knowledge gained through needs and capacity assessment studies undertaken as mentioned above, a table consisting of qualitative scoring against different parameters for six geospatial application products over the three thematic areas is developed (Table 1). The assessment included seven major variables with 22 subvariables addressing information needs, development, and uptake. The land cover change assessment monitoring and forest biomass quantification are the two applications considered as part of forest-based climate change mitigation programs of Ministries of Forests and Soil Conservation. The crop sown area and condition assessment are the two application considered to support Nepal Food Security program of Ministry of Agriculture Development. The multiscale disaster risk assessment and flood risk decision support system to strengthen flood risk reduction systems operated by Ministry of Home Affairs, Nepal. In this article,

Table 1 Needs and Status of Geospatial Applications over HKH Region-2010 (Based on Stakeholder discussions held as part of NASA-SERVIR-Himalaya program during 2010) (3 = High, 2 = Medium, 1 = Low)

	Forest carbon mitigation		Season crop monitoring		Flood DRR	
	Cover monitoring	Periodic carbon assessment	Area assessment	Condition assessment	Risk reduction	Early warning
1. Needs/application						
Direct/basic	3	3	3			3
Complimentary				3	3	
Periodicity	3	3	3	3	2	3
Long-term need	3	3	3	3	3	3
2. Databases/tools/systems available						
Historical/current databases	1	2	1	1	1	1
Standard procedure/methods followed	2	1	1	1	1	1
Operational systems	2	2	1	1	1	1
3. Awareness						
Strategic level	2	1	2	2	1	1
Operational level	2	2	3	3	3	2
4. Expertise available						
National	2	2	1	1	1	1
Local	1	1	1	1	1	1
5. Ground operational systems						
Infrastructure	3	2	1	1	2	1
Dedicated expertise	2	2	1	1	1	1
Information uptake systems	2	1	2	2	2	2
Recurring budgetary support	NIL	NIL	NIL	NIL	NIL	NIL
Inter institutional systems	1	1	3	3	3	3
6. Technology operational systems						
Open access satellite data continuity	3	3	3	3	2	2
Open access software	1	1	2	2	3	2
Reliable operational methods	2	1	3	3	2	1
Open access dissemination tools	3	3	3	3	3	2
7. Information use						
Government	2	2	1	1	1	1
NonGovernment	1	1	1	1	1	1

we focus on the experiences and challenges regarding geospatial data and information availability, user capacities on product development and use. A very limited discussion on scientific methods and accuracies followed during product development will be mentioned, whereas such details can be obtained from supporting references.

3 Agriculture and Food Security

Agriculture is the most important livelihood sector in the HKH region and provides a substantial proportion of rural income and employment opportunities to its estimated 210 million inhabitants. Typically, the very nature of subsistence-oriented farming is structured around a traditional weather calendar based on undisturbed climate (Vedwan and Rhoades 2001). The dramatic climatic and environmental changes that are taking place in the Himalaya are reported to have profound impact on the conditions for food production. Alongside socioeconomic changes including economic globalization, increasing accessibility, and land use conflicts, dynamic demography is affecting the subsistence agriculture systems across HKH region. Geographical constraints often restrict the flow of goods to and from isolated areas; landslides, mud falls, and soil degradation not only adversely affect crop yields and farming practices but also restrict transport and the advantages it brings.

Food security is a significant challenge in the HKH region, where the harsh biophysical conditions and short growing seasons constrain agricultural productivity and can create food deficits (Kurvits et al. 2014). As a so-called climate change hotspot, climate change, and extreme weather events like floods and droughts are projected to impact food security in mountain regions like the HKH particularly hard (Murthy et al. 2014). Recent vulnerability assessments show that over 40 % of households in the mountainous region of the HKH are facing decreasing yields in their five most important crops as a result of floods, droughts, frost, hail, and disease (Bhandari et al. 2015).

A few of the basic challenges addressing food security in the region lies on how to improve the underlying productivity of natural resources and cropping systems to meet increasing farmers demand and to produce food which is safe, wholesome and nutritious and promotes human well-being. Case studies on agricultural transformation of mountain areas show how farming of High-Value Crops (HVC) has increased food security and employment, thus improving living conditions for mountain people (Badhani 1998; Partap 1999; Sharma and Sharma 1997; Tulachan 2001). The development of multifunctional agriculture systems, sustainable management of mountain agriculture practices such as terrace agriculture, shifting cultivation, developing narrow climate, and geographic niche-based local cropping systems, evolving resilient productive systems against climate disasters, improving water efficient and high crop intensity regimes in low elevations are a few priority areas which require scientific support and policy-level interventions on a continual basis. On the other hand, the development of effective communication systems and improved accessibility are also identified as potential windows through which useful and timely information and material would reach the farmers to face both environmental and social challenges.

Recent developments in use of Earth observation satellite data in combination with ground-based information, can reveal valuable information about environmental conditions that can subsequently impact the livelihoods of farmers. A Geographic Information System (GIS) and remote sensing technologies are helpful to identify regions experiencing unfavorable crop growing conditions and food supply shortfalls and to determine food insecure areas and/or populations (Minamiguchi 2004). Similarly, increase in use of Information Communications Technologies (ICTs) in facilitating rural development by providing agricultural extension services and real-time market price information, availability of rural payphone can play a significant role in enhancing the ability of rural families to continue, and perhaps enhance their contribution to national agricultural production and postharvest activities (Anderson and Bows 2008). These scientific and technological interventions involve in-depth operational research and application with a focus to leap forward into useful ground applications. In this context, an understanding of the current capacities on technological and user operational segments and the future scenario and needs over the decade in adoption of EO-based actionable information would stand as most supporting information.

3.1 Current Scenario Assessment

In the current national food security assessment system across the region, the District Agricultural Development Offices are responsible for the collection of crop situation data from field for national- and subnational-level analysis. These well-placed traditional systems need to be strengthened for better decision-making using substantial capacity developed for crop condition monitoring and production estimation using EO systems. Globally, satellite remote sensing has become an integral component of operational agricultural monitoring systems, enabling crop analysts to track development of growing season, and provide actionable information to decision-makers for developing effective agricultural policies and timely response to food shortfalls (Wu et al. 2014; Zhang et al. 2010). Yet, the lack of synergistic use of space and ground-based systems in the HKH region is limiting the potential of spatially explicit decision-making processes and translating the knowledge as crop advisory systems. The integration of satellite-based climate and soil moisture information with crop growth models is urgently need to allow for and improve assessments of drought scenarios and crop yield estimations and forecasts.

Across the HKH region, differentiated capacities and operational systems prevail, requiring different levels of technological intervention (Table 1). For example, the significant efforts are being made through FEWSNET program in Afghanistan and in Pakistan, The Pakistan Space and Upper Atmosphere Research Commission

(SUPARCO) in collaboration with provincial agriculture departments of Sindh and Punjab in Pakistan, has recently established satellite-based crop monitoring system, where high-resolution optical data acquired during peak growth seasons of February for rabi crops and September for kharif crops to assess seasonal yield forecast for major crops. However in Nepal, Bangladesh, and Myanmar, the adoption of remote sensing data is at very preliminary level. While there is a general agreement on significant need on such information, there are no dedicated institutional setup and expertise available. Practitioners in operational positions tend to possess moderate experience in remote sensing technology, but such awareness at higher strategic levels is very limited. On the other end of the spectrum, targeted end users of remote sensing products have very low technical expertise in interpreting technically complex products. This stresses the need for developing more customized and actionable information.

The recent efforts of NASA/SERVIR-Himalaya in developing national crop and drought monitoring systems over Nepal using satellite-based information and their integration with quarterly food security bulletins of Ministry of Agriculture and Development and World Food Program reveal possible leads could be achieved through effective user involvement. However, formidable challenges remain for the EO community in downscaling the national-level near-real-time crop monitoring systems into farm/site-level advisory systems, designing systems to effectively inform evolving operational crop insurance mechanisms, and improving Agro-Pastoral, Silvi-Agro-Pastoral flows and linkages to enhance livelihoods over high-altitude Himalayas.

3.2 *Prospects and Challenges*

The small farmer holdings, mixed crop conditions, persistent cloud cover, rain fed systems experiencing temperature stress, diseases, and land degradation are a few of the key elements within food security domain, where EO and improved sensors need to play vital role. The frontier technologies and modeling frameworks should help to integrate local knowledge with scientific data and technical skills to improve knowledge on mountain-specific traditional production systems, as well as local cropping systems within narrow climate and geographic niches. Given that unique climate and geographic niches often occur across boundaries, frameworks for regional and transboundary collaboration are important. Such frameworks would promote international benefit of technology interventions that would otherwise not be realized if only national perspectives are considered.

3.2.1 Crop Identification and Monitoring

A summary of the availability and continuity for remote sensing data products for the effective agriculture monitoring in the HKH region is give in Table 2.

Table 2 Needs and challenges of geospatial application—agriculture development in HKH region

Thrust areas/crop types	Current systems (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segments (2015–2030)
Major cereal crops	• Medium resolution Optical + SWIR (MODIS 250 m, MERIS 300 m)	• Continuity of similar system SAR (Sentinel-1A, 1B)	• Improving accuracy of subnational agriculture statistics
High-altitude local crops	• Medium to high-resolution Optical + SWIR and Hyperspectral data (Landsat 30 m, CBERS, Hyperion) • No such data available	• High-resolution Optical + SWIR (Sentinel-2) • High-resolution multispectral data	• Introducing basic GIS/Mobile apps to agriculture extension staff • Significant technology effort to be made on methodology standardization to develop microwave-based crop area estimates
Crop sown area	• Medium resolution Optical + SWIR (MODIS 250 m, MERIS 300 m) • In season sown area assessment generated • Time lag in generation, reliability of estimates due to elimination of small crop holdings, cloud infestation effects the operational use	• High-resolution Optical + SWIR (Sentinel-2) with high temporal capability, better radiometric resolution • Availability of Microwave sensors to address could effects	• Introducing area-frame sampling approach and integration of UAV
Crop stress	• Medium resolution Optical + SWIR Landsat TM Water stress, disease stress-based operational methodologies lacking • Use of satellite/model-based soil moisture inputs lacking	• Continuity of similar systems Landsat TM type of sensor with additional bands of red edge and moisture • Experimental Hyperspectral data • SMOS-based/similar products assimilation to be achieved	• Improving infrastructure on automated ago-met stations • Research efforts/projects to be implanted over red edge and hyperspectral-based pilot studies • Pilot studies on soil moisture assessment and integration to be introduced
Crop advisories	• Reliable real time spatial climate data, stream flow, soil moisture products almost lacking • Crop production models integrating hydromet data, soil moisture, crop specific data as above are at research level	• Integrated regional specific models to developed to provide policy and operational level crop advisories	• Research studies on developing region specific spatial hydromet products and crop production models to be augmented

The current MODIS/SPOT-based temporal crop monitoring systems need continuity with more customization in data processing and delivery mechanisms linking diversity of users. The improved spatial resolution, as well as, enhanced radiometry are required for achieving better accuracy to assess small farmer holdings, and discrimination of mixed cropping systems. Most of the rice crop is grown in kharif season (monsoon), coinciding with the over cast cloudy conditions of the sky most of the time. The dedicated microwave missions, data access mechanisms, and R&D to identify observables needed in terms of polarizations, frequencies, and spatial and temporal resolutions are essential to study kharif season crop growth systems. High-resolution thermal infrared data along with shorter wavelengths (VIS, NIR and SWIR) would enhance the process modeling pertaining to energy and water balance and characterizing thermal environments of the agricultural crops. This would help toward estimating the water requirements/evapotranspiration which is useful in modeling crop stress and productivity in the context of rainfed and drought scenario.

Atmospheric effects are significant source of errors in multitemporal analysis of satellite data over the mountain regions. This calls for inclusion of specific atmospheric correction channels or independent atmospheric correction sensor to facilitate estimation of atmospheric parameters such as water vapor content and aerosol optical thickness in the upcoming sensors. Toward improving the accuracy of surface parameters, retrieval multiangular observation system is required for determining the Bidirectional Distribution Function (BRDF). This could be implemented with multiangle imaging sensor of five views having four bands in VNIR region. The improved information and knowledge from such new sensor systems could extend extensively to food production and availability components of food security in mountainous regions.

3.2.2 Supporting Food Security Through Agro Advisories—Moving Across Scales

Negative impacts of climate trends on crop production have been more common than positive impacts, as evident in some high-altitude regions. There have been several periods of rapid food and cereal price increases following climate extremes in key producing regions, indicating a sensitivity of current markets to climate extremes, among other factors affecting the food availability (Trostle 2010). In addition, the episodic response of food production to climate also impairs the supply chain systems of local people, threatening food availability. EO-based crop monitoring and geospatial models on crop productivity provide only a partial assessment of food security–climate change relationships in terms of food production and not specifically on food availability.

It is of particular concern how to link this multitude of information to policy-based issues involving sustainable development communities, assessing and ensuring food security prospects. Engagement of these policy communities requires much a broader and comprehensive scalable framework to translate productivity and production information from crop and farming systems respectively to food security systems. The geospatial technology plays a critical role in monitoring, assessing, and modeling food production through crop simulation models, continual monitoring of growth profiles over crop cycle, crop production estimations using spectral and ground-based yield data, and risk assessment, with the goal of minimizing losses and improving production stability against natural disasters (Belmonte et al. 2003; Grigera et al. 2007). The applicable satellite systems on precipitation (GPM) and soil moisture (SMAP) and regionalized climate forecast systems constitute primary information support needed for crop growth monitoring systems (El Sharif et al. 2015). In addition to biophysical monitoring, information on different farm specific local practices, agronomic challenges, and regional micro- and macroeconomics are drivers of food production and availability. This emphasizes that significant coupling of information across scales and disciplines is needed to understand linkages of food production and availability (Fig. 2; Table 2).

In order to move across sectoral scales, the EO community could play a critical role in coupling environmental models (e.g., climate forecasts, hydro-meteorological dynamics, crop growth, and productivity) with spatial econometric models. Such an effort is only possible with joint efforts of multiple expert communities, relevant subject domain experts, and policy-level decision-makers. Currently, such efforts are far from beginning in this region, and hence call for long-term multi-institutional initiatives to address the serious problems of food security exacerbated by climate change.

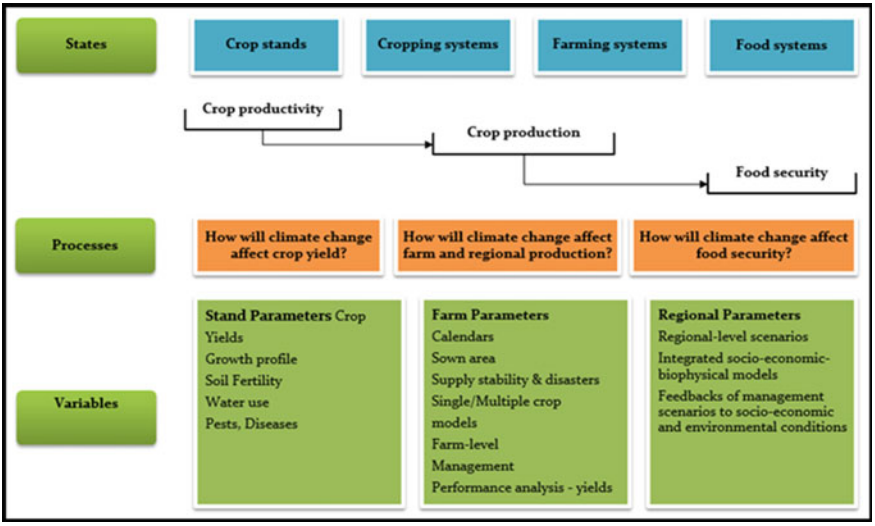

Fig. 2 Climate change impacts and food security moving across spatial scales: From crop production to food security

3.2.3 Alleviating Food Distress Through Bio-Resources Management

The high-altitude Himalayan livelihoods largely comprise of natural resource-based subsistence ecosystems. Apart from less agriculture land availability, the harsh climate, rough terrain, poor soils, and short growing seasons often lead to low agricultural productivity and food availability. The sustained food security hence is also determined by grasslands function and associated livestock patterns, availability of forest-based resources, and balanced inter flow of material regulating these three interconnected ecosystems. The mountain-specific practices like terrace cultivation, shifting cultivation, narrow niche-based cropping systems, multifunctional agriculture, and harnessing local water springs become pertinent in such areas. The Agro-Pastoral, Silvi-Pastoral, and Silvi-Agro-Pastoral systems also stand as great players in the region. By looking at HKH region mountain farming trends, Tulachan (2001) suggests focusing on crop–livestock farming systems, which will pose less pressure on common property resources such as forests and community lands, leading to positive impacts on the environment.

The effective functions of interactive ecosystems are largely governed by local innovations and practices of indigenous and local communities embodying traditional lifestyles. This is demonstrated in the wisdom developed over many generations through holistic, traditional, and scientific utilization of the lands, natural resources, and environment. It is generally passed down by word of mouth, from generation to generation and is, for the most part, undocumented. However climate change, globalization, and increased disasters are forcing many livelihoods to shift toward new practices like unsustainable production of cash crops, water harvesting, and use of pesticides in agricultural fields, leading to vanishing traditional cultural practices. While traditional knowledge is valid and necessary, however in the age, it is only beneficial when blended with enormous contemporary scientific knowledge. The adaptability to new practices requires appropriate infrastructure and scientific knowledge associated with vulnerability, disaster management, and unsustainable extraction of bioresources to ensure food security.

In this context, EO systems and associated geospatial technology play promising roles at multiple scales for understanding local practices, relevance, and changing internal and external drivers. Contemporary EO systems and models are natural frameworks to integrate downscaled high-resolution climate forecasts, high-resolution Digital Elevation Models (DEMs), large-scale land cover and bioresource inventories, crop and rangeland calendars and productivity, land degradation, and spatial explicit ecosystems services assessment and flows (Table 2). Such comprehensive biophysical information previously not available could be integrated with traditional knowledge and practices and social and economic drivers, through agent-based models, spatial econometric models, and other self-learning algorithms to delineate or stratify socioecological regimes across large bioclimatic regions of the high-altitude systems.

Locations and characteristics of such socioecological strata as defined by a certain degree of similarity in structure and function would constitute a cluster of food distress units. These clusters could be further studied using three models:

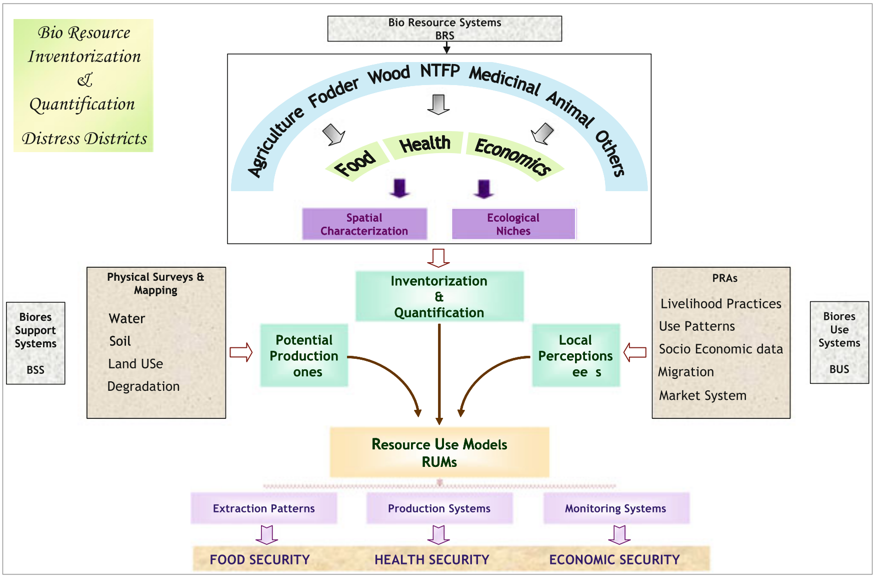

Fig. 3 Bioresource inventorization and quantification

(1) bioresources capital system, (2) bioresources support system, and (3) bio-resources use system. The integrated analysis of these different systems on spatial and temporal dimension would provide alternate scenarios of ensuring food security through sustainable management of bioresources. The different components of three subsystems and integration frameworks are given in Fig. 3.

The pilot testing and implementation of best possible scenarios across food distressed villages provide model concepts of bridging traditional and scientific knowledge for ensuring food security. Such an approach would also provide a framework for upscaling over the similar socioecological strata identified elsewhere. In this light, it necessary that the EO community reaches the last mile to stakeholders to implant technological bottom-up simple innovations, developing coupled traditional and scientific knowledge bases, cost optimization, and scalability. The strengthening of local participatory and governance systems, identifying appropriate capacity building needs and institutionalization, are also very critical to effective application of EO to addressing food security challenges.

4 Forest-Based Climate Change Mitigation

Carbon sequestration, carbon substitution, and carbon conservation are the processes through which forests can contribute to the mitigation of climate change. Contrasting a typical Land cover, Land-use and Forestry (LCLUF) approach, an

Agriculture, Forestry and Other Land-Use (AFOLU) approach greatly expands the potential for carbon sequestration in the land-use sector with greater benefits for the countries of the HKH. The forests of HKH region are estimated to mitigate 3500 megatons (MT) of carbon through avoided deforestation and degradation and 47 MT of carbon through improved forest management over next 20 years. Therefore, flexible, robust, credible, and well-tested Sustainable Forest Management (SFM) and integrated land-use management frameworks are needed to support the simultaneous reduction of carbon emissions, sequestration of carbon, and ensured provision of ecosystem goods and services.

The Collaborative Partnership on Forests (CPF) consisting of 14 major forest-related international organizations, institutions, and secretariats, developed the strategic framework on forest-based carbon mitigation and climate change. Among the six critical messages of the framework, one of the messages stresses the need for reliable, consistent, and continual information support to develop effective assessment and diagnosis, planning, implementation, and monitoring. In addition to the strong local context-based knowledge and action, the use of geospatial information emanating from multisensor remote sensing information is strongly advocated both for mitigation and adaptation strategies (IPCC 2006).

Globally, the practice of using geospatial science-based evidential information has significantly increased with the advent of open access satellite data, information products, mobile, and web-based data collection and dissemination platforms (Elwood 2010). However, due to differentiated capacities of HKH countries, there is a wide gap in terms of: (1) application and use of geospatial systems for forest cover change assessment and monitoring, (2) cost effective multiscale carbon monitoring to support the Reducing emissions from Deforestation and Forest Degradation (REDD) strategies, and (3) evolving planning and monitoring strategies for forest-based vulnerability and adaptation planning (Boyd and Foody 2011). Periodic land cover change assessments, forest degradation assessments, and biomass quantification, stand as three fundamentals for forest-based carbon mitigation strategies.

4.1 Current Scenario Assessment

A significant effort has been made over the region in developing periodic national land cover change data bases in the region as part of ICIMOD regional collaboration with regional member countries through the NASA-SERVIR-Himalaya initiative (Gilani et al. 2015a, b; Uddin et al. 2015). The details of current status on data availability are given in Table 3. However, dedicated operational systems and framework are lacking to produce periodic change assessment. Globally available annual tree cover and global change monitoring systems using Landsat TM data need significant improvement for regional-level applications. Satellite-based community-level forest cover monitoring and degradation assessment tools using high-resolution data are at research stage to bring out cost effective, user friendly open source methodologies (Gilani et al. 2015a, b).

Currently, assessment of forest growing stock is done at national and subnational levels. National growing stock estimates are developed using national-level multisource forest inventories. In order to address sustainable forest management, the national forest inventories are made exhaustive in terms of parameters and data collected across the entire country. Most of the national inventories follow systematic sampling with fixed grids and proportional temporary and permanent sample points chosen for data collection. In view of this complexity, national inventories involve intensive field sampling and are thus time and cost intensive. The estimates are generally planned over a 5-year time interval. However, due to time and cost constraints, biomass assessments in most HKH countries, apart from China and India, have not been carried out at regular intervals to support the need for forest carbon monitoring (Du et al. 2014; FSI 2011).

Equally, national-level growing stock estimates over large countries do not provide realistic subnational scenarios, while the next lower level assessments done at the district level are designed with district-specific requirements in terms of sampling design and time. The application of satellite remote sensing in optimization of cost and time to produce periodic biomass assessment is at early stages of application. Significant emphasis has been placed on developing such information, awareness, and expertise at both operational and at strategic levels, and institutional frameworks exist across the different countries of the region. However, improvements are needed on scientific methods being followed as well as on capacity building efforts on developing operational frameworks and assimilating new technologies to address periodicity, reliability, cost, and turnaround time.

4.2 Prospects and Challenges (up to 2030)

4.2.1 Land Cover Change Assessments

In recent years, at the global level, numerous efforts have been made to provide satellite-based medium-resolution land cover and forest cover information. Most commonly used are Landsat images, which are of long standing and widely used for continuous land cover monitoring (Gong et al. 2012; Hansen et al. 2013; Kim et al. 2014). At the global to regional level, these data products are developed through supercomputing techniques to provide reasonable results. At the national levels, more coordination, collaboration and ground validation are very much needed. Further synergies between national and global and regional partners need to be established. At this stage, significant effort needs to be made, to improve operational frameworks on Monitoring, Reporting, and Validation (MRV), ranging from ground data collection techniques to institutionalized delivery and use of products. The land cover monitoring needs in HKH over the next decade definitely require data continuity from Landsat TM type of high-resolution satellite systems. The local scale, very-high-resolution-based land cover change assessment is in its infancy in HKH due to several operational constraints. The likely challenges for the next decade are likely to be open source object-based algorithms, cost effective very-high-resolution data, scientific and technical expertise, and necessary infrastructure development (Table 3).

4.2.2 National Biomass Estimations and Mapping

In the current forest carbon estimation systems, excessive cost related to extensive field measurements and spatially inconsistent estimations along with limited control on uncertainty due to errors from allometry and sampling design are major challenges to addressed through new tools and approaches (Lei et al. 2009). Also for conservation management strategies, there is a need to determine the essential measurable properties such as species distribution, stand density, basal area, and canopy density that describe the forest vegetation and also influence the forest biomass/carbon stocks (Kim et al. 2010; Kwak et al. 2007; Lovell and Graetz 2001; Yang et al. 2013). According to the Intergovernmental Panel on Climate Change Good Practice Guidance (IPCC GPG) (IPCC 2003), remote sensing methods are especially suitable for independent verification of national LULUCF carbon pool estimates, especially for the aboveground biomass. Remote sensing instruments and techniques (space borne/airborne) are widely in use for forest cover monitoring, biomass estimation, mapping, and accuracy assessments at local, national or regional scales (Baccini et al. 2004; DeFries et al. 2007). Most of the developing countries do not have forest inventory data to get accurate biomass figures. Furthermore, several methods have been proposed for estimating forest biomass using remote sensing techniques that make use of a combination of regression models, vegetation indices, and canopy reflectance models (Cho et al. 2012; Gonzalez et al. 2010; Huang et al. 2013; Kajisa et al. 2009). Remote sensing-based biomass estimation, mapping, and accuracy have increasing attraction for scientists (Ahmed et al. 2013; Foody et al. 2003; Franklin and Hiernaux 1991; Lu 2006; Nelson et al. 1988; Steininger 2000; Zheng et al. 2008). Gibbs et al. (2007) reviewed different remote sensing data sets by discussing the befits, limitation, and uncertainty.

Approaches that make full use of remote sensing techniques to estimate Above Ground Biomass (AGB) are therefore needed (Le Toan et al. 2011). To overcome this issue, NASA's Global Ecosystem Dynamics Investigation Lidar (GEDI) is planned to launch in 2019. GEDI will use a laser-based system to study a range of climates, including the observation of the forest canopy structure over the tropics, and the tundra in high northern latitudes. This data will help scientists better understand the changes in natural carbon storage within the carbon cycle from both human-influenced activities and natural climate variations (Stysley et al. 2015). The European Space Agency (ESA) the BIOMASS Mission is also planned to launch in 2020 from 70° N to 56° S with accuracy not exceeding ±20 % (or ±10 ton/ha in forest regrowth) with forest height with accuracy of ±4 m at spatial scale of

Table 3 Needs and challenges of geospatial spatial applications—land cover and forest degradation at national and local level

Thrust areas	Current system (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segments (2015–2030)
National level			
Land cover	• Consistent periodical land cover change data available except Myanmar • Dedicated operational systems and framework lacking to produce periodic change assessment • Global annual Tree cover monitoring system available using LANDSAT TM and MODIS data needs improvement in terms of product type and quality	• Continuity of Landsat TM type of sensors • Regionalized automated algorithms and provision of computing platforms attracts users to adopt space-based monitoring systems	• Significant effort need to be made to evolve operational framework on monitoring, awareness expertise and institutionalizing • Synergies with global and regional partners to be established • Research studies on regional algorithms to take place
Forest degradation	• Landsat-based periodic crown closure changes used as one of the measures. Need to be made operational	• Operational algorithms to be evolved on crown closure change assessments as terrain effects and shadows limits reliable classification • Adoption of red edge and moisture-based remote sensing studies shown significant promise on degradation assessment. • Availability of red edge, moisture and thermal sensors on similar lines of ASTER is very important.	• Significant research studies dovetailed with user needs to take place
Local level			
Land cover	• Satellite-based community forest monitoring tools using high-resolution data are at research stage • Cost and technology optimization and framework for operational use lacking	• Multispectral high-resolution sensors systems are limited, need for developing countries in spatial planning process is critical, open source object-based algorithms and S/W are lacking to analyses high-resolution images	• Enhanced localized EO planning acquisitions helpful (e.g., from International Space Station (ISS) platforms such as ISS-SERVIR Environmental Research Visualization System (ISERV) or other) • Interventions of GEO or Systems like International Disaster charter, Subsidy provisions from commercial systems are a few cost optimizations to be attempted • Research focus to go on object extraction algorithms

(continued)

Table 3 (continued)

Thrust areas	Current system (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segments (2015–2030)
Degradation assessment	• Critical need exists to support community forestry programs promising research and operational aspects to be tested • Very limited studies were available	• Future satellite systems should consider this global need of local degradation assessment, large proportion of stakeholders for space data could belong to this community, sensors on the similar lines RapidEye supported with 1 m BW will be in demand	• Research work on piloting, demonstration, capacity building is needed. Involvement of global expertise is important • Studies on linking to national scales and packaging for use at local level as simple monitoring tools is challenge

100–200 m (Le Toan et al. 2011). Another NASA-ISRO Synthetic Aperture Radar, Mission (NISAR) is also in pipeline to be launched in 2020. According to Alvarez-Salazar et al. (2014) NISAR's unprecedented coverage in space and time will reveal biomass variability far more comprehensively than any other measurement method.

In the HKH region, where steep terrain and complex forest characteristics can play problem for accurate inversion of the satellite data, robust validation efforts based on field measurements are needed. Although, sporadic efforts in the form of filed campaign are being made to produce national and subnational measurements. A more structure effort and network of institutions are needed to bring the validated satellite products and to make them available for national usages.

Capacity building and long-term technical back stopping are also essential to strengthen the local partners who can take advantages of global products. Indigenous human resource adequately trained with new technology will ensure continuity of efforts as well as influence the decision-making process.

4.2.3 Forest Degradation Assessment—REDD MRV Systems

A few of the critical challenges of REDD MRV systems are reliable estimation of deforestation, afforestation, forest enhancement, and degradation. Currently, fairly good satellite-based global to sub national monitoring systems are available to monitor forest cover gain and loss (Gibbs et al. 2007). However, quantification of changes in carbon fluxes due to forest cover change dynamics is still a complicated task (Sasaki and Putz 2009) and stands important as it contributes to larger proportion of carbon dynamics. The national-scale degradation assessments to quantify carbon fluxes are related to timber and fuelwood extractions, grazing, and fire impacts (Miettinen et al. 2014). Significant efforts need to be made to provide crown closure changes-based degradation assessment to support carbon assessment using remote sensing data. At the national level, operational algorithms to be evolved on crown closure change-based forest degradation assessment. Availability of red edge, moisture and thermal sensors, and application are important for detection of changes and mapping degraded areas. However, such national approaches are not suitable at local scale community forestry systems due to lack of driver data and microlevel canopy changes. In this context, adoption of community-based forest monitoring tools involving local stakeholders is being tested as one of the alternate systems. Danielsen et al. (2011) have explained the role, accuracies, and economics of community-based, forest-based monitoring systems. The community-based monitoring systems involve scientifically identified permanent sample plots over individual community forest areas, developing protocols and training and periodic measurements of different parameters at specified intervals (Poudel et al. 2014). One of the critical challenges of these community-based monitoring systems is efficacy of low-intensity permanent sample points representing the large area under study, lack of spatial extrapolation power to address changes beyond the sample plots such as forest cover losses and degradation over the entire study area (Härkönen 2002). In such a case, difficulties also arise in the inability of point-specific measurements to reliably quantify carbon dynamics due to leakage, additionality, and persistence. In an effort to handle these challenges, integration of remote sensing systems with field-based measurements are being evaluated to assess potential application and operational feasibility for community-level MRV systems (Palmer Fry 2011) addressing challenges on detecting local-level changes and integration with local filed monitoring systems. Remote sensing-based spatial explicit estimates provide wall to wall coverage, enabling decision-makers, and managers to understand the dynamics beyond point-based estimates (Baccini et al. 2012; De Sy et al. 2012). Integration of forest measured and monitoring data collected by the local communities with satellite systems could provide precise and accurate reporting of degraded hotspots (Fig. 4). Affordable, very-high-resolution multispectral data is going to be a huge need in the context of upcoming REDD initiatives to enable assessments of local species and stand-level degradation and biomass change assessment (Table 4). The adoption of multiresolution satellite systems also helps to address biomass estimations at species-, stand-, and forest-type levels, enabling a spatial linkage of different scales of information to reach from community level to national estimates.

5 Flood

The HKH region encompasses high-mountain landscapes and is prone to natural disasters of myriad types due to active geotectonic setting, sensitivity to climate extremes, fragile ecology, large degree of poverty, lack of infrastructure, and poor accessibility to services. An increasing trend in the recurrence of natural disasters and associated impacts due to floods, glacial lake out bursts, landslides, and forest fire is reported over HKH region. The total recorded major disasters events during 1900–1910 to 2000–2010 have increased from 7 to 617 involving millions of human and economic losses, even when not considering local-level events. The

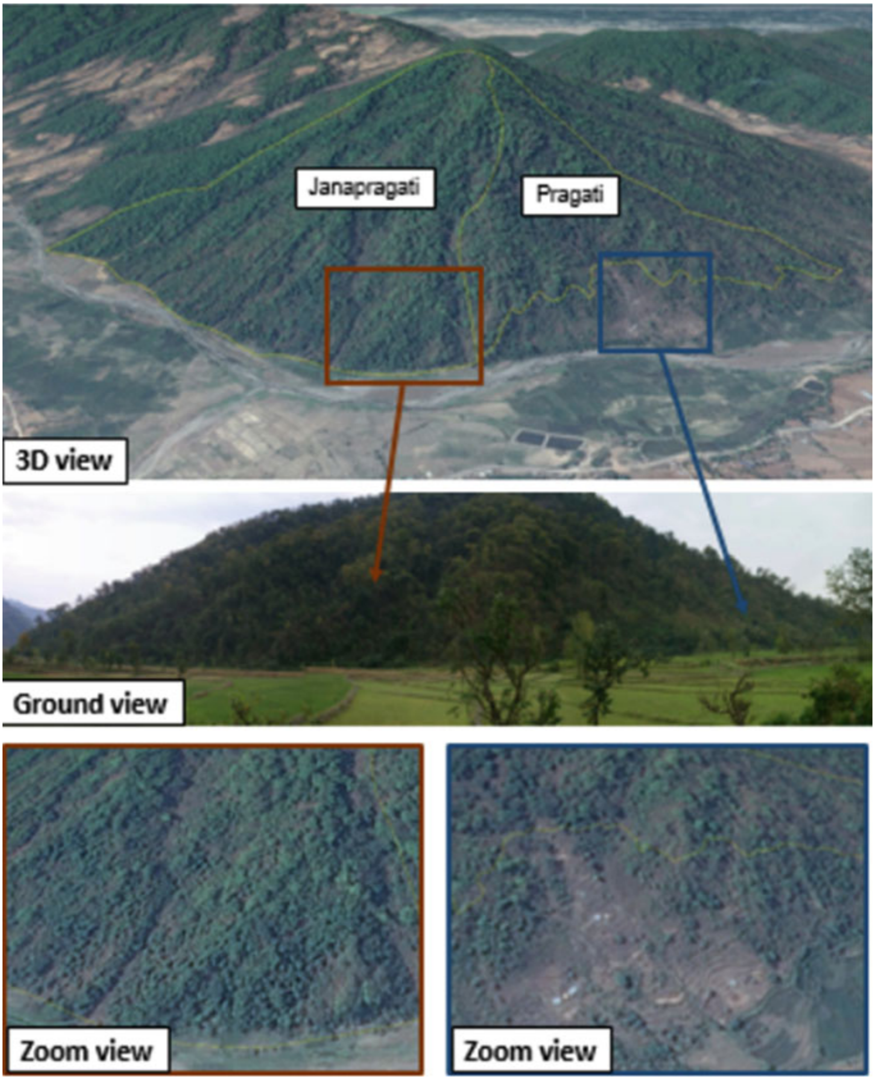

Fig. 4 Synchronization of satellite images and ground photographs

unprecedented scale of disaster events like flood (Fig. 5), landslides, and forest fire in recent years are found to have close links with increasing incidents of extreme climate events. In addition, rapid but unsustainable development, population explosion, and economic development in the HKH region are expected to inflate the cost of flood impacts.

The uncertainties involved in understanding high-altitude land surface and atmospheric processes and extreme climate dynamics are identified as primary

Table 4 Needs and challenges of geospatial spatial applications—forest carbon monitoring at the national and local level

Thrust areas	Current system (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segments (2015–2030)
National carbon accounting	• National growing stock assessment designs and measurements in place. • Limited interventions from remote sensing takes place to improve sampling designs and estimations • Periodic assessments, needs and framework lacking to support monitoring carbon fluxes	• Sampling designs and demonstrations involving optical, microwave and LiDAR data depicting cost and data optimization required • Regional microwave-based height retrieval algorithms are needed	• Capacity building on microwave-based biomass assessments and spatial modelling at user end is an urgent need • Ground campaigns through mobilization of local forest communities under the guidance of forest officers
Community carbon monitoring	• Community-level field-based monitoring tested in a few countries • Complimentary use of remote sensing and field technology to enhance thematic content and cost optimization to be implanted	• Species- and canopy-level proxy indicators and stratification, canopy geometry and species-based parametric and nonparametric models to be developed	• Research collaboration, technical training and infrastructure development needed

factors for such increased risk. To overcome these challenges, we need to invest on innovative and low-cost systems to develop reliable predictive models and tools with monitoring capabilities that integrate local knowledge and ensure timely communication of actionable information. A significant need to build long-term resilience against disasters, acting upon hazard and risk by building robust and planned infrastructure and mitigation systems is also advocated.

5.1 Current Scenario Assessment

The role of geospatial tools which includes both remote sensing and GIS in spatial planning in the context of different thematic focus, including disaster has long been recognized in flood management (Abdalla and Li 2010; Goodchild 2006; Tahir 2007; Uddin et al. 2013). The improved availability of operational all-weather capability satellites, constellation of satellite systems, satellite-based rainfall mapping and estimation systems, Unmanned Aerial Vehicles (UAV), low-cost

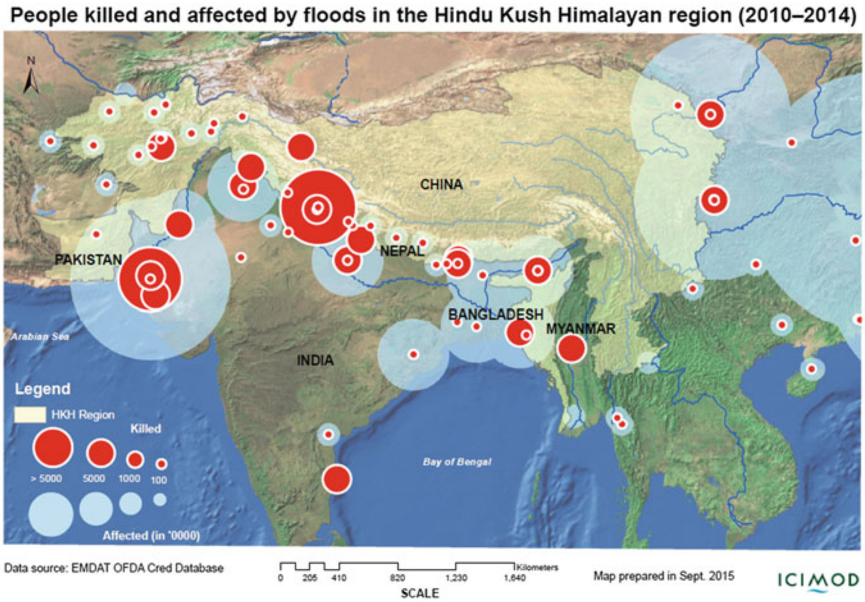

Fig. 5 HKH causality by flood

ground-based sensors, mobile-based communications, spatially explicit simulation and statistical models, and open access high-resolution data and information products have improved globally the efficiency of disaster early warning and emergency response systems.

The cooperation among regional and international agencies in terms of data sharing, response synergies, and risk reduction platforms are also contributing to the disaster management. During the last decade, HKH countries stand high in invoking and obtaining support from the International Charter for Space and Major Disaster for disaster response. The current level of adoption of these systems across the region is presented in Table 1. These seed attempts need be to further strengthened as several technological and institutional gaps and challenges do exists which needs to be addressed over the coming decade. The major thrust need to be drawn on flood risk reduction systems consisting reliable flood risk reduction information and early warning systems which are described as below.

5.2 *Prospects and Challenges*

5.2.1 Flood Risk Reduction Information and Planning

The Sendai Framework articulates amongst others, the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics to mainstream Disaster Risk Reduction (DRR) in development through risk informed policy and investment (Sendai Framework for DRR 2015–2030). Risk informed policy and investment has become imperative in view of rising trend of extreme events due to climate change, and rapid economic development on the other hand compromising safety concerns. Tracking loss and damage associated with natural hazards at national and subnational levels help us monitor the impacts of disaster, thus forming the basis for risk informed policy and investment, and a means to evaluate success of DRR investment. Pre- and Post-2015 framework for DRR puts emphasis on "Record, analyse, summarize and disseminate statistical information on disaster occurrence, impacts and losses," (Sendai Framework for Disaster Risk Reduction 2015–2030).

An overview of the status, gaps, and challenges on evolving geospatial support for disaster risk reduction systems is given in Table 5. The spatial delineation of flood risk zones using historical flood events, inundation maps, land cover, settlements, topographic variability, drainage patterns, and river network have been prepared as a case example for a watershed in Nepal to support planning and reduce associated life and property losses (http://apps.geoportal.icimod.org/raptiflood). However, the currently available risk reduction databases over highly critical areas are not appropriate available and if available are not for operational working at local level. The availability of local scale high-resolution DEM, infrastructure and settlements databases, and inundation scenario for various return periods and incremental rainfall situation has been a serious gap of information and is of urgent need in the HKH region.

The adoption of very-high-resolution data due to cost constraints and lack of reliable feature extraction algorithms in developing such information also needs to be addressed. The calibration and development of open source physical models to incorporate run off and inundation scenarios to support operational planning is of urgent need. The development of Decision Support Systems (DSS) to integrate and analyze such diverse thematic datasets to support informed decision-making for pre-flood risk reduction planning at local levels is also lacking. The technology demonstration with cost effective and user friendly DSS has still to go a long way in the region. These database and information systems are also most needed during flood emergencies for damage assessment, relief, and recovery operations. The cross-sectoral institutional understanding and institutional strengthening toward evolving national disaster emergency data infrastructure, associated policy support systems, integration with traditional knowledge systems, and adoption of DSS on the similar lines of China and India is of immediate need.

In this regards, the recent collaborative effort of Ministry of Home Affairs (MoHA), Nepal and ICIMOD, Kathmandu under SERVIR-Himalaya program on establishing online multiscale disaster information and risk assessment is worth mentioning (http://apps.geoportal.icimod.org/disaster/). It is essentially based on a decade-long disaster loss database from MoHA. The online product is directly relevant to policy makers and planners to make risk informed policy decisions and investments through better comprehension of disaster and impact in the temporal and spatial perspectives. The system provides temporal trends of disaster impacts

Table 5 Needs and challenges of geospatial spatial applications—flood risk reduction planning

Thrust area/response, recovery	Current systems (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segment (2015–2030)
High-resolution terrain	• 2–5 m DEM available over limited area • 90 and 30 m DEM in public domain	• Ortho rectified DEM needs to be prepared • Higher resolution DEM needs to be generated over critical flood plains	• Ground-level local organization to be involved and strengthened
Infrastructure/settlement inputs	• Less than 1 m data-based mapping of vulnerable areas lacking	• Feature extraction algorithms, periodic data updating • Data cost optimization mechanisms to be addressed	• Significant research on feature extraction • Local institutional involvement to be addressed
Inundation inputs	• Inundation maps produced based on optical data • Optical data limited by cloud cover • Microwave-based maps not in operational use • Processing of microwave data in steep terrain still a big challenge	• Operational data availability mechanisms and algorithms • Cost optimization methods to be optimized • Collaboration with Global Flood Monitoring System (GFMS)	• Dedicated SAR mission less than a day revisit, all-weather capability, satellite constellation
Real time damage assessment	• MODIS and Landsat TM used but do not meet all needs due to resolution limitations • Significant limitation in providing damage related inputs in real time • Lack of framework to integrate data sources from multisensors and systems	• Strengthen hydrological modelling approaches and undertake research to prepare inundation maps • Large swath, high-resolution, high-temporal optical data to provide coverage within less than 1 day • Continued availability of SAR missions on open access basis • Possible synergies between low Earth orbit (LEO) and available geostationary orbit (GEO) systems in the region	• Ground segments capability to process high temporal and spatial data products • Satellite constellation, formation flying concepts • Microwave-based algorithms and processing capacities at ground • Research studies on LEO-GEO integration studies

represented by loss of lives and economic loss, a basis for evaluating success of DRR interventions at national, district, and subdistrict level. The local scale DSS helping flood risk planning developed over local watershed of Nepal is an another good example. Similarly, great relevance exists to develop such systems over Bangladesh, Bhutan, Myanmar, and Pakistan.

5.2.2 Flood Risk Reduction and Flood Early Warning

Flood management necessitates the real-time event capture both spatially and temporally. Disaster events like floods, for example, are relatively faster in nature, having different temporal and spatial dimensions than drought and crop pests/diseases, which are slow onset types. This necessarily calls for critical inputs from EO systems. The significant cloud cover problems during flood seasons in the HKH region necessitate all-weather capability EO systems. The quantification of catchment physical characteristics, such as topography and land use, and catchment variables such as soil moisture and snow cover supporting flood risk reduction are well supported using high and low-resolution polar orbital earth resource satellites. However, there has been a significant weakness in turnaround time in providing reliable information during flood events in the region. The reliable medium-term climate forecasts, real-time inundation levels and associated damages have been always a limiting element from EO systems (Table 6). It is important to progress toward all-weather capability systems to: (i) increase time and frequency of coverage, (ii) improve coverage access and delivery, (iii) increase resolution of Digital Terrain Model (DTM) for local applications—this includes very local (1 m) information (town, small watershed, etc.), and (iv) achieve the ability to access EO products and services on real and near-real-time basis.

The satellite constellation with elements of autonomy and 'formation flying' mode on a long-term basis should aim to provide less than a day revisit and all-weather capability. The suite of satellite systems of LEO, GEO satellites, and a dedicated SAR mission would add substantial strength to real-time monitoring of the floods and also capturing the moving targets like cyclones (Table 6). There are several global and regional LEO systems and GEO systems of China and India operating over the region. However, there is no significant effort made to assess the realistic quantitative assessment on synergetic benefit of all these systems, associated gaps, and challenges. Most of the collaborations and responses are limited to the emergency response during flood events thorough international space charter. These aspects should be discussed at international GEO summits or evolving regional GEOs to evolve more synergistic suite of satellite systems. The disaster monitoring satellite if launched is perhaps one of the first attempts in this direction. The regional partners need to be encouraged to participate in such global missions before launch for fruitful product development and use.

One of the major challenges in the context of floods is on the understanding of climate and its variability. It necessitates studies on various atmospheric parameters and processes leading to operational applications and predicting major climatic events with high accuracy. The aim would be to deliver reliable climate information in useful ways to maximize opportunities for decisions and help to minimize risks due to floods. In this context, the efforts from SERVIR on providing climate data and forecasts through ClimateSERV are worth mentioning (http://climateserv.nsstc.nasa.gov). The real-time and effective use of GPM and SMAP missions to provide regional products is one of the important elements for the coming decade, especially in terms of validating and customizing products. Such efforts could lead to reduced

Table 6 Needs and challenges of geospatial spatial applications—flood early warning systems of HKH region

Thrust areas	Current systems (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segment (2015–2030)
Real time satellite and station blended rainfall data and delivery	• Limited use of TRMM 3B42V7, TMPA, CMORPH, GSMaP, CPC RFE • Limited efforts on blended data, limited efforts to adjustment or modify in precipitation retrieval algorithm in mountainous region in HKH region • Limited tools: Geo-WRSI	• Adoption of GPM data and blending • Undertake research to fill critical gaps in those fields, modify precipitation retrieval algorithms in mountainous region in HKH region • Integration with new satellite missions • Integration with Geosynchronous systems of China and India • Adoption of high-resolution Integrated Multisatellite Retrievals for the Global Precipitation Measurement Mission (IMERG) precipitation product	• Significant research on GPM validation, awareness to take place • Pilots on customized products • Partnerships with national systems and agencies and global teams and efforts
Communication system	• Dependent on local network, not dependable during disaster event • Satellite systems are very expensive	• Service from communication satellite systems to be made affordable	• Active participation of national organizations
High-altitude observatory	• Very scattered, lack of resilient and dedicated systems • Difficulties in ground maintenance • No opportunities for mountain (HKH) specific mission	• New Innovations in instrumentation, recording and survey against all-weather capabilities • Installation of AWS to validate the space products	• Significant research and funds should be engaged to observe, measure, assimilate into scientific and decision-making systems
Soil moisture	• Very limited awareness and use of Satellite-based Soil Moisture Products	• Adoption of SMAP data, blending and integration into hydrological and landslide models	• Significant awareness building and research on validation and application of SMAP data and new sensors
Rainfall forecasts	• No dedicated national forecasts 3–4 h of lag (latency) time—critical for flash flood • Limited use of Global forecast system (GFS) data or Global Data Assimilation System (GDAS)	• Integration with global efforts on short and long-term forecast • Improve global forecasts with local surface and ground data	• Global collaboration efforts in evolving regional systems need to be focused

(continued)

Table 6 (continued)

Thrust areas	Current systems (2010–2015)	Technology continuity/new systems (2015–2030)	Ground segment (2015–2030)
Run off/flow levels	• Hydrological models used • Satellite Altimetry models over plains are being attempted	• Adoption of GFS data generated by IMD, and Weather and Research Forecast (WRF) data generated by ICIMOD • Improved hydrological forecasts using better satellite-based input information as above • Altimetry models to be further tested • Continuity of Altimetry-based sensors • Dedicated SAR Mission (regional hydrology) • Satellite Constellation-Less than a day revisit, large swath, high-resolution optical sensors • Small satellite missions process understanding • Improve regional coordination and sharing of data	• Significant research on hydrological modelling models to be strengthen Institutional linkages and traditional knowledge systems to be integrated to make actionable products

uncertainty in climate projections by providing timely information on the forcing and feedbacks contributing to changes in the Earth's climate. The blending of national hydromet measurements systems and regional hydromet systems like HYCOS with GPM missions would enable the provision of real-time climate information for both flood forecasts and flood damage assessments. In addition, real-time applications of satellite altimetry-based flow information in conjunction with regional specific in situ measurements and hydrological models on evolving flood warning systems as developed in Bangladesh should be further tested. A summary of progressive events leading to development of effective flood early warning and risk management systems is presented in Fig. 6.

5.2.3 Flood Emergency Response

Emergency responders and managers need near-real-time situation reports as flooding unfolds to be able to appropriately deploy response interventions. Traditional data collection means are limited in timely and updated information gathering at wider geographical scope. Satellite data with wide viewing scope and high temporal frequency when considered in unison with multiple sensors bridges this critical gap, effectively feeding in near-real-time information into

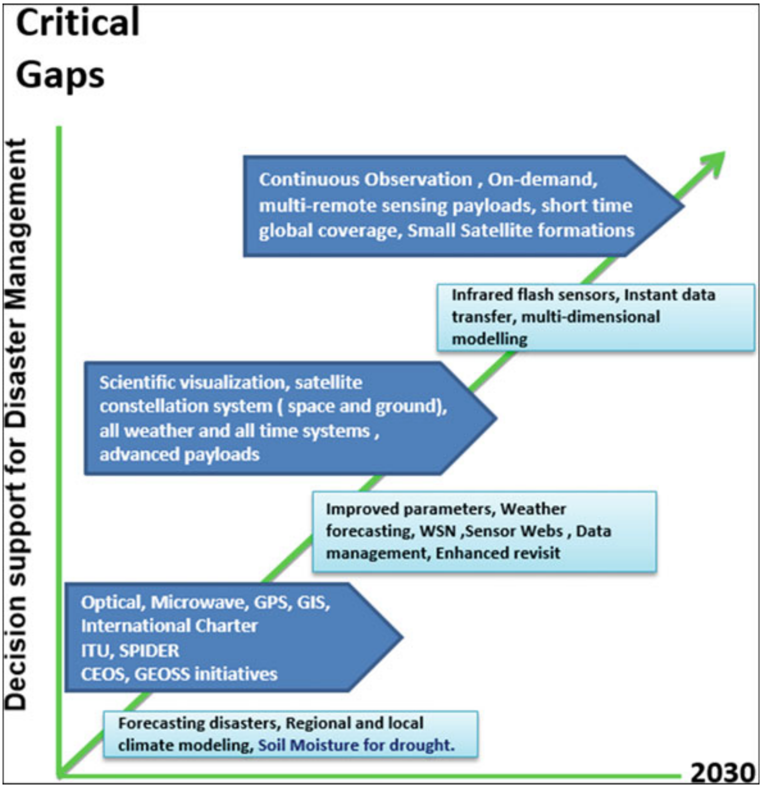

Fig. 6 Summary of progressive events leading to development of effective flood risk management systems

decision-making processes. Advances of space science are now able to provide multispectral satellite images with submeter spatial resolution of any corner of the Earth. Under ideal environmental situations, satellite-based mapping can provide information on progression of flood hazards, pockets of vulnerable exposures, and safe sites for evacuation, minimizing impact from the event. On the software side, there are algorithms to automatically delineate inundation layers to map flood extent and assessment of situation when event happens. Cloud cover precludes ground observations and poses a major challenge, but microwave EO satellite systems have shown a lot of promise in overcoming this challenge. Operational challenges with microwave systems are affordability, inadequate temporal frequency, and need for rigorous processing techniques to adequately address terrain influence, especially in the HKH region.

The role of models in flood scenario development, though a proven concept, is challenged by unavailability of exposure data and necessary input data such as rainfall and topography. Rainfall pattern in mountainous terrain are affected by orographic influence and current satellite-based rainfall product (GPM with 0.1°

spatial resolution) do not capture rainfall distribution and spatial variability adequately. There is need for satellite-based rainfall products with higher spatial resolution to capture spatial variability of rainfall for improving discharge estimates and inundation scenario.

The internet has revolutionized the way information sharing and delivery happens. Internet-based delivery systems reliant on elaborate infrastructure are often absent in disaster prone far-flung communities, where decisions must be made that are often not within national delivery mechanisms. Mobiles services, despite remarkable penetration, have not reached many poor communities living in disaster prone area. Moreover, SMS-based delivery mechanisms, despite being a preferred communication mechanism, have not made the difference as one would expect (http://sm4good.com/2013/05/02/code-conduct-sms-natural-disasters/). A new form of delivery mechanism needs to evolve such that it operates in conjunction with community-based DRR apparatus. Satellite-based communication systems such as VSAT are still limited by high cost, and unless high-value infrastructure are involved it is often not the choice. Solutions targeting developing countries need to be simple and cost effective so that scaling up of the system is not hindered by management and financial constraints.

6 Conclusions

The HKH mountains serve as globally significant natural resource regimes and climate regulation systems. In the context of climate change and transboundary issues, the understanding of mountain ecosystems needs utmost priority and importance. There is an urgent need to orient EO efforts to characterize, monitor, and model the mountain systems in the way designed to study oceans and atmosphere. Current satellite-based EO systems and associated products play a limited role in understanding high mountain cryopshere dynamics, associated hydrology regimes, and the erosion of ecosystem services. The ability of current ground sensor networks is also limited in monitoring high-altitude climatology, atmospheric chemistry, and dispersion, vegetation stress degradation of biodiversity and associated services.

Primary efforts for the region with respect to EO include the validation and customization of satellite-based rainfall and soil moisture products, their integration into climate and hydrological forecasts, and building end-user capacity and strengthening institutions that can benefit from EO. The future endeavors should also focus toward better quantification of snow/ice depth to understand precursors of hydrological dynamics, disaster vulnerability, and upstream/downstream dynamics across nations (water availability, life security). This should facilitate packaging EO observations into more reliable, readily usable and customized region specific climate services related to natural resource and disaster sectors. Essential EO-informed products needed to support mountain livelihoods will be easy-to-access and interpret, and be of high-spatial and temporal resolution. It will cover vegetation composition, stress, and productivity for food security and ecosystem services assessment, disaster support information for response and recovery, and vegetation degradation and biomass maps to address carbon monitoring. The combined use of satellite, ground and model-based studies to monitor and assess land degradation and air quality also contributes to ecosystem health.

All these applications needed to be packaged into Essential EHVs in line with ECVs and provided on turnkey basis through global and regional cooperation on the similar lines MODIS value-added products. The EHVs underlines the concept of converting information into *actionable products and services*. In this context, various global efforts like WRI, Silva carbon, WMC, GEO, NASA, MAIRS and SAARC, and regional/national efforts would be closely networked through a dedicated mountain centers and platforms such as ICIMOD. An improvement on the currently disaggregated nature of these projects would be to work on a more programmatic basis.

The different dimensions of enhancements in EO capabilities are required to develop above-mentioned products. A few of the critical to address include:

- Improved satellite-based stereogramatic capabilities to understand and quantify snow and ice depth
- Oriented and customized sensors and products to better monitor and forecast mountain climate
- Satellite constellation systems to enhance repetitive cover to address disaster and resources monitoring-related aspects
- Strengthening advanced planning and data acquisition systems for disasters
- Active sensor (microwave)-based turnkey products for disasters
- Short-term experimental small satellites to study geophysical and biophysical mountain complexities
- Satellite—Sensor webs to address problems like flash floods, glacier melts, and glacier lake outbursts
- High radiometric and spectral channels-based systems to monitor ecosystem processes, invasion, stress, productivity, and water quality

These developments could only be realized through the integration of appropriate ground measurement and validation systems. The lack of reliability or nonusage of ground-based information/data while developing sophisticated models and algorithms are found to ultimately minimize the accuracy, dependability, and use of global turnkey products. The following would strengthen the region:

- Provision of common pool data
- Development and provision of algorithms and products to encourage replication, improvements, and utilization
- Strengthening of forecasting abilities and related systems
- Cloud computing platforms

With the advent of developing and availability of tailor-made services, the user capacity building efforts should focus more on services specifications, potential application, need and method of integration with local datasets for value-added services, sustainability, and institutionalization approaches.

It is also essential to reorient and enable user segments so as to achieve enhanced uptake of actionable products. These efforts could include:

- Popularizing and bringing larger awareness among users
- Infusing local flavor to dissemination systems
- Empowering simple local mechanisms, institutions, and uptake systems
- Developing and building dedicated a larger tier and network of policy, scientific, and local user communities
- Introducing key facilitators and practitioners who can take actionable products to a diversity of users
- Enhancing the layperson's understanding of the use of online web applications and ability to contribute more accurate data through crowd source systems.

The weak bridge between researchers/products and policy makers on the utilization of available satellite resources should be addressed as one of the major capacity building initiatives in the HKH countries. Integration of global expertise and experience in blending innovation mechanisms with local knowledge both from top-down and bottom-up approaches facilitates for policy advocacy at local scales. Regular interaction between researchers and application developers with policy makers for better understanding and ensured uptake of EO-informed systems is also necessary. While these approaches and mechanisms are standard, the major focus has traditionally been oriented toward service development with minimal policy support. Focusing on drawing policy support for EO service use is the formidable challenge to overcome in the coming decade to ensure EO systems advance the last mile toward sustained use.

Acknowledgement The authors thank ICIMOD and NASA for all the support in developing this manuscript. We also thank NASA- and USAID-supported SERVIR-Himalaya program for the necessary support to undertake the current scenario assessment. The views expressed by ICIMOD authors are at individual level and do not necessarily represent the institution.

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http://www.springer.com/978-3-319-33436-3

Earth Science Satellite Applications
Current and Future Prospects
Hossain, F. (Ed.)
2016, VIII, 284 p. 72 illus. in color., Hardcover
ISBN: 978-3-319-33436-3