GISCIENCE IN THE MOUNTAIN GEOGRAPHY

Krishna Poudel*

ABSTRACT

Mountains have distinct geography and are dynamic in nature compared to the plains. 'Verticality' and 'variation' are two fundamental specificities of the mountain geography. They possess distinct temporal and spatial characteristics in a unique socio-cultural setting. There is an ever increasing need for spatial and temporal data for planning and management activities; and Geo Information (GI) Science (including Geographic Information and Earth Observation Systems). This is being recognized more and more as a common platform for integrating spatial data with social, economic and environmental data and information from different sources.

This paper investigates the applicability and challenges of GIScience in the context of mountain geography with ample evidences and observations from the mountain specific publications, empirical research findings and reports. The contextual explanation of mountain geography, mountain specific problems, scientific concerns about the mountain geography, advances in GIScience, the role of GIScience for sustainable development, challenges on application of GIScience in the contexts of mountains are the points of discussion. Finally, conclusion has been made with some specific action oriented recommendations.

THE MOUNTAIN GEOGRAPHY

Mountains are the most prominent features of the landscape on the earth surface covering 15 to 20 percent of land area (Ives 1989: 289) and exist in almost all continents. These mountains are the homeland of about 10 percent of total human population (Grotzbach and Stadel 1997) and provide livelihood for several millions more. Mountains of the world are dispersed in all continents with different location, direction and extensions. Mountain geography is highly varied and complex. The physiographic characteristics of the mountains of all continents have some commonalities whereas the human and socio-economic dimensions, potentialities, of resources intensity of natural disasters and development perspectives have large diversities and variations (Stone 1992). Many spatial complexities are visible and active on determining the surface, sub-surface and interior forces of landscape changes. Mountains are highly sensitive because of their geophysical and geological basement and are also highly fragile because of their outer surface morphometry like slope, elevation, aspect, coverage, and other human induced activities. Several sudden and local scales to global and long-term events and threats are directly associated with the mountain environments. The United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio in 1992 had identified three major environmental issues facing the global community in the 21st century namely climate change, biodiversity and desertification. The follow up World Summit held in Johannesburg South Africa

*Associate Professor, Central Department of Education, Tribhuvan University, Kathmandu, Nepal

in 2002 reviewed progress after the Rio Summit. The Summit has pointed out that over 600 million people living in the mountains and foothills are within the direct impact of the climate changes and retreat of mountain glaciers (United Nations University 2005). The Human Development Report (2006) clearly indicates that the rural and urban slum areas of the world are under the severe water crises and closely interconnected with poverty, poor health condition, vulnerability and powerlessness (UNDP 2006). The distribution of the area under severe water crises covers the mountain region of the world.

MOUNTAIN PROBLEMS

The mountains of the world's geographic regions have different sets of problems (Heywood et al. 1994). Most of the problems are interconnected, with the demographic characteristics of the people, their resource endowments, and geographic, social, cultural, and governance regulatory factors (Poudel 2003) with intricate linkages between upstream and downstream. The African mountains have a high population density with increasing altitude (MRI 2007). A large number of people derive their livelihoods from the fragile slopes of the African highlands. The Asian mountains have comparatively less people living in the elevated parts; large masses of people live in the lower foothills and floodplains which are connected to the highland-lowland chain of environmental degradation (Stone 1992, Blaikie and Muldavin 2004). The European mountains have sparse populations, but large parts of mountain areas are increasingly coming under tremendous pressure from the tourists. Similarly, large portion of the mountains of the world are under the frontier, politically sensitive, unrest and war, zone of drug production and trafficking. (Stone 1992)

Mountain regions of the world, including the Hindu Kush-Himalayas (HKH), bear a special significance in the global ecosystem. The HKH region is home to the largest concentration of glaciers outside of the polar region signifying the 'water-tower' of Asia. The mountains of the HKH region not only provide freshwater, they are also biodiversity hotspots. The HKH mountain ecosystem provides life support services to almost a third of humanity (ICIMOD 2007). Extending some 4000 kilometers from Afghanistan in the west to Myanmar and eastern part of China in the east, this mountain region is the highest as well as one of the most sensitive and fragile landscapes (Jodha 1992, Zurick et al. 2005) in the world. The region is also confronting issues like poverty, environmental degradation, natural resources depletion, shrinking water resources, desertification and climate change, as well as threats of natural disasters like earthquakes, landslides, and floods. More pronounced impacts of climate change and the rise in earth surface temperature in mountain areas have been reported by various sources (Mol et al. 2001, MRI 2007, Shrestha 2007a, Bajracharya et al. 2007). Studies suggest that the warning in the Himalayas has been much greater than the global average of 0.74^0C over the last 100 years (Bajracharya et al. 2007, Jianchu et al. 2007) and it is one of the most vulnerable regions of the world due to climate change.

SCIENTIFIC CONCERNS

The scientific discourse on the Himalaya-specific environments, livelihoods, natural and human-induced disasters began in and around the 1960s still rages. Sporadic case studies, small geographical coverage, short-time span of studies, unreliable sources of evidence, vested interests behind studies, and subjective judgments of the facts have been some of the major weakness in examining problems and generalizing the results in the Himalayan environment (Thompson and Warburton 1985, Ives and Messerli 1989, Blaikie and Muldavin 2004). The sporadic bursts of attention given to mountain areas have generally been a post-disaster phenomenon (Banskota an Jodha 1992)

Chapter 13 of Agenda 21 of the United Nations Conference on Environment and Development (UNCED) 1992 emphasized upon raising public awareness and ensuring adequate policy level, institutional, and financial commitments for concrete action towards implementation of sustainable mountain development. Following UNCED, mountain ecosystems have been increasingly gaining world attention as global life support systems. This has also been duly recognized with the proclamation of 2002 as 'International Year of Mountains (IYM) by the United Nations General Assembly, which culminated with the adoption of the Bishkek Mountain Platform as a common guide to ensure the sustainable development of mountain regions. The platform for the 'International Partnership for Sustainable Development in Mountain Regions' was launched at Johannesburg during the World Summit on Sustainable Development (WSSD) in the same year. These international events have duly emphasized the need for geo-information and earth observation systems for decision making in support of sustainable mountain development (United Nations University 2005).

Enormous technical challenges face the mountain environment owing to specificities like rugged terrain, steep slopes, inaccessibility, and inherent socio-ecological characteristics. Sustainable development requires accurate and reliable databases and geographic information that adequately capture the specific characteristics of mountains both from spatial and temporal dimensions. There is growing recognition by the scientific community of the need of quality databases for better scientific understanding and the need for sharing them among concerned stakeholders (Rhind 1997). One of the major challenges facing the mountain region is limited availability and accessibility of geo-information and affordable tools and methods for mountain specific cases. For instance, the recent IPCC4 reports the HKH region as a 'blank spot' in a global climate map (IPCC 2007). There is a need for concerted efforts by relevant stakeholders to bridge the geo-information and knowledge gaps in the region to support its sustainable development.

ADVANCES IN GISCIENCE

Geographic Information Systems (GIS) were devised in the 1960s as computer applications for handling volumes of information obtained from maps as well as for performing operations that would otherwise be too tedious, expensive, or inaccurate to perform by hand (Aronoff 1989, Peuquet and Marble

1990). Recent trends have been toward the development of GIScience and Technology (Goodchild 2004).

The last decade witnessed an unprecedented growth and development in earth observation data and applications. Earth observation techniques through Remote Sensing (RS) are proving to be more cost effective than ground-based techniques over large areas. RS data have the benefits of the synoptic view of a large area, which helps in obtaining the proverbial 'bird's eye-view' of the features, especially of inaccessible mountainous terrain. Furthermore, there has been an emergence of high-resolution satellite data in recent years with greater degree of spatial and temporal variations than ever before. Similarly, Global Positioning System (GPS) technology provides the ability to compute and capture position anywhere on the earth's surface with 24-hour coverage. Systems like Google Earth and Microsoft Virtual World have revolutionized the way we access and visualize satellite-based information seamlessly from local to global levels with unprecedented level of details.

Advances in information and communication technology combined with earth observation technology and geographical analysis and modeling tools are now available to quantify, model, document, and disseminated information on key socio-economic, environmental, and natural resources conditions and trends. This convergence of information technology (remote sensing, global positioning system, light detection and ranging (LiDAR) have provided effective and promising tools and methods for dealing with diverse mountain issues. Geo-Information (GI) Systems have emerged as powerful tools in integrating and analyzing information from divergent sources and presenting the results in an effective and efficient way. These factors have led to the creation of a suitable context for institutional and technological framework for the use and access of geographic information for improved decision-making.

THE ROLE OF GISCIENCE FOR SUSTAINABLE DEVELOPMENT

In order of capture the opportunities offered by GI technology and applications, the United Nations organizations and several other international and national organizations are playing an important role in embracing a spatial data infrastructure (SDI) framework at the local, national, regional, and global levels (Campbell and Masser 1995). Building infrastructure for spatial information is becoming as important as the building of physical infrastructure such as roads and telecommunications infrastructure. Spatial Data Infrastructure (SDI) has been conceived as an environment where - the basic geographic datasets are readily available; existing geographic information are well documented; available geographic information conform to accepted standards; policies encourage sharing and exchange of geographic information; and adequate human and technical resources are available to maintain and manage geographic information. It can be seen as the broad policy having organizational, technical and financial arrangements, necessary to support access to geographic information.

The importance of geospatial data infrastructure has been highlighted in United Nations documents in a global perspective (UNGIWG 2007). The United

Nations charters have clearly emphasized in their mandates the application of global spatial data infrastructure and earth observation satellite for humanitarian, poverty, environmental management, and disaster application in a wider scale (UNGA 2004). An intergovernmental body, the Global Earth Observation System of Systems (GEOSS) was established in 2005 with a view to promote co-ordinate efforts to bring the benefits of Earth Observation (EO) applications for environmental and humanitarian purposes.

The status of GISciences and their applications are diverse and varying in nature. For instance, China and India have their own earth observation satellite systems, while Bangladesh, Nepal and Pakistan have established remote sensing data centers in the early 1970s. During the early days, very few applications were concerned with the mountain development. GIScience applications have emerged since the early 1990s as useful tool for the development of mountain areas in the region. In Bhutan a major work was initiated to prepare country-wide satellite-based maps for land use planning. With assistance from UNDP Afghanistan established the Afghanistan Information Management System (AIMS) for GI and EO application.

ICIMOD established the Mountain Environmental Resources Information Systems (MENRIS) in 1990 to promote and use geographic information systems (GIS) and remote sensing (RS) technologies and applications for integrated mountain development (ICIMOD 2006). The primary objective was to improve environmental and natural resources management and promote sustainable economic growth, by facilitating solutions to common problems and ensuring the communication of results on a compatible GIS platform. MENRIS works as a resource centre for the HKH region for the study and application of GI applications and has successfully developed partnerships with key international organizations, space agencies, software vendors, and the network of national institutions in the region.

CHALLENGES ON APPLICATION OF GISCIENCE

Mountains have high degrees of heterogeneities and complexities. The availability and collection of geographic data in mountain regions is affected by historical, political, climatologically factors, and by high spatial variability of topography, diverse natural resources and vegetation, and many other factors. The vast diversity of mountains, both in terms of biophysical and socio-cultural aspects, makes it extremely difficult to delineate homogeneous units where management and policy implications can be applied and compared. Also, the sets of available and recorded data are often not comparable because of differences in scale and accuracy. Furthermore, many regional issues extend beyond the national border and need to be considered as a homogenous unit across borders. There are a number of transboundary concerns in the region, such as climate change, biodiversity conservation, management of water resources, mountain hazard mitigation, and others.

Amidst these contextual settings, geographic information applications in mountainous regions present considerable challenges. GIS is a 'post industrial technology' developed for the needs of North America and Europe and applying this technology in the developing countries generally poses considerable challenges (Heinimann et al. 2003). Heywood et al. (1994) observed a common set of issues that are data-related, organizational and technical in nature in the application of GIS in management and research in the mountain context. In the case of the HKH region, there is a need for sustained efforts toward greater utilization of GI applications (Shretha 2007b) by focusing on three major issues: a) capacity building and networking, b) mountain database, tools and methods, and c) thematic application and decision support systems.

A qualified and capable human resource is the fundamental component for successful utilization of GIScience application. Although the use of its application has been advocated to understand various socio-ecological and natural processes in the region, it is important that the scientists and planners first understand the technology itself for its appropriate utilization. GIS is a multidisciplinary tool. Partnerships and networking among different institutions are keys to successful capacity building in GIS and EO applications (Shrestha and Bajrachary 2007). Continuing efforts have to be exerted to induce public and private institutions, including the academic sector, to promote in-country teaching and training capacity in GIS and related applications. In particular, Universities can play a significant role in formal GIScience and education to fill the human resources gap over the longer term. The private sector has an emerging role in providing specific training and services for a growing GI market in the region.

Data issues related to availability, accessibility, acquisition, management, and sharing are prevalent in the region. Specific mountain studies recommend high quality database inputs to minimize errors in computation of the Digital Elevation Model (Wechsler 2007), distance measurement, and accurate scale for mountain cartographic mapping (Cassel-Gintz et al. 2007). There are challenges associated with tools and methods of acquisition of cost-effective database for the mountain region. Furthermore, remoteness poses difficulties in validating the correctness of EO data on the ground. Goe-information in the region is often dispersed, heterogeneous, and inaccessible. The demand for good, reliable, and homogenous data on mountain areas has been clearly established in scientific circles and at the levels of national, regional and international organizations. Mountain-specific spatial data infrastructure is, therefore, a prerequisite to the creation of an enabling condition for the use of GI applications (Shrestha and Bajracharya 2007).

The high degree of heterogeneities of mountain areas, and the vastly different rates of change in their physical, biological, and societal systems, present challenges for GI applications and spatial decision support systems. Compared to the plains, the physical characteristics of mountains are complex and need to be analyzed incorporating the 3rd dimension features to arrive at an approximated representation of topography, slope, and aspect. Challenges also concerns upstream-downstream linkages in evaluating mountain ecosystem services, and transboundary and multi-disciplinary applications. Differences in cultures, languages and traditions also pose additional challenges.

CONCLUSION AND RECOMMENDATIONS

Mountain characteristics provide ample room to exploit GI technologies; however, large bulks of current GI applications in the region are confined to specific area-problem based cases, with relatively small and national geographic coverage. Lessons learnt from the past over a decade long capacity building and networking on GIScience and technology has strongly envisaged the mainstreaming goe-based solutions and up-scaling and strengthening regional geo-information network with a new strategic vision. The developed information communication technology is a strong asset for the effective networking. GIScience and technology has to build in an interdisciplinary subject vision. The developed information communication technology is a strong asset for the effective networking. GIScience and technology has to build in an interdisciplinary subject framework. Many issues of human poverty, environmental degradation and climate changes interrelated in a cross boundary jurisdiction of conventional scientific school level could result a multiplier effect among the youth which is highly required for sustainable mountain development. A new strategy of the knowledge sharing at regional level on effective GIScience based methodology, curricula, and criteria have to be developed. Strategic alliances and customizing international knowledge, and innovation and regional platform are required to establish in the mountain region. Human resources are most important asset and the development of qualified GIScience expert is a challenge. As UNGIWG (2007) emphasizes that "UNSDI is not just about technology and data the challenge face is to build up the human resources so that they can use these tools and data to ensure that UNSDI can effectively support informed decision making".

Mountain geography has large complexities. Physically difficult and inaccessible location, politically sensitive geographical units, different production capabilities, geopolitically strategic locations etc are common characteristics of the mountains. Because of these difficulties it needs to build the capacity of local organizations and institutions to gather, access, maintain and update database at local level. It has to develop a Mountain Geo-Spatial Database Infrastructure (MG-SDI) in a broad perspective of application as a guideline for the national institutions and to play a lead role on MG-SDI policy intervention on GIScience and technology. A network of national geographic information infrastructure has to be developed to share the geospatial database. Satellite imageries of various levels of sensors with different spectral bands can be used to collect mountain database for different spatial and temporal resolution.

GIScience and technology is developing with its fast pace. It is a technology driven, however, the reduction of hardware and software prices are encouraging factors for the implementation of GI technology in the limited financially capable institutions of the mountain region. The technology has to utilize for the large share of the population in terms of their welfare. Specifically in the mountain context, the GI technology can be applied for the identification of the 3-dimensional surface i.e. slope, altitude and aspect. These are the fundamental morphometric parameters of the mountain. Problems and potentialities of the mountain determine from these three basic properties. GIScience, therefore, is an indispensable discipline which needs to embrace with no question in the mountain geography.

WORKS CITED

Aronoff, S. 1989. *Geographic Information System: A Management Perspective.* WDL Publishers, Ottawa, pages 294.

Bajracharya, S.R., P.K. Mool and B.R. Shrestha. 2007. *Impact of Climate on Himalayan Glaciers and Glacial Lakes: Case Studies on GLOF and Associated Hazards in Nepal and Bhutan.* ICIMOD, Kathmandu.

Banskota, M. and N.S. Jodha 1992. *Mountain Agricultural Development Strategies: Comparative Perspectives from the countries of the Hindu Kush-Himalayan region.* pages 83-114 in N.S. Jodha, M. Banskota and T. Pratap (editor). *Sustainable Mountain Agriculture: Perspectives and Issues.* Vol I, Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, India.

Blaikie, P.M. and J.S.S. Muldavin. 2004. Upstream, Downstream China, India: The Politics of Environment in the Himalayan Regions**.** *Annals of the Association of American Geographers*. 94(3):520-548.

Cassel-Gintz, M., A. Heinimann and U. Wiesman. 2007. *The Scale Challenge in GIS-based Planning and Decision Making in Mountain Environments.* Urban and Regional Information Systems Associations (URISA), Illinois, USA.

Campbell, H. and I. Masser 1995. *GIS and Organizations: How effective are GIS in Practice?* Taylor and Francis, London.

Goodchild, M.F. 2004. GIScience, Geography, Form and Process. *Annals of the Association of American Geographers*. 94(4):709-714.

Grotzbach, E. and S. Christoph. 1997. *Mountain People and Culture.* Pages 17-38 in B. Messerli and J.D. Ives (ed.). *Mountains of the World: A Global Priority.* The Parthenon Publishing Group, New York and London.

Heinimann, A., T. Breu and T. Kohlor. 2003. The Challenges of Applying Geographic Information Systems to Sustainable Mountain Development**.** *Mountain Research and Development.* 23(4):312-319.

Heywood, D., P. Ian, F. Martin and J.R. Petch. 1994. *Mountain Regions and Geographic Information Systems: An Overview.* Pages 1.24 in Martin F. Price and D. Ian Heywood (editors). *Mountain Environments and Geographic Information Systems.* Taylor and Francis, London.

ICIMOD, 2006. *ICIMOD: Achievements, Challenges, and Lessons Learned.* International Centre for Integrated Mountain Development, Kathmandu.

IPCC, 2007. *Intergovernmental Panel on Climate Change: Fourth Assessment Report Climate Change 2007: Synthesis Report.* Intergovernmental Panel on Climate Change, Valencia, Spain.

Ives, J.D. 1989. *Mountain Environments*. Pages 289-345 in G.B. Martini-Bettolo (ed,) *Study Week On: A Modern Approach to the Protection of the Environment.* November 2-7, 1987. Pergamon Press, New York.

Ives, J.D. and B. Messerli. 1989. *The Himalayan Dilemma: Reconciling Development and Conservation.* Routledge, London and New York.

Jianchu, X., A Shrestha, R. Vaidya, M. Eriksson and K. Hewitt. 2007. *The Melting Himalayas Regional Challenges and Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods* (ICIMOD Technical Paper). ICIMOD, Kathmandu.

Jodha, N.S. 1992. *Mountain Perspectives and Sustainability: A framework for development strategy.* Pages 41-82 in N.S. Jodha, M. Banskota and T. Pratap (editors). *Sustainable Mountain Agriculture: Perspectives and Issues.* Vol. I, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

Mool, P.K., S.R. Bajracharya, and S.P. Joshi, 2001. *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Mountain and Early Warning Systems in the Hindu Kush-Himalayan Region, Nepal.* ICIMOD, Kathmandu.

MRI. 2007. Global Change Research Network in African Mountains, Makerere University 23-25 July 2007 (Workshop proceedings). *Mountain Research Initiatives.* Switzerland.

Peuquet, D.J. and D.F. Marble 1990. *What is a Geographic Information System?* Pages 5-99 in Donna J. Peuquet and Marble F. Duane (editors). *Introductory Reading in GIS.* Taylor and Francis, New York.

Poudel, K.P. 2003. *Watershed Management in the Himalayas: A Resources Analysis Approach.* Adroit Publishers, New Delhi, pages 361.

Rhind, D. (editor) 1997. *Framework for the World Goe-Information International*, Cambridge.

Shrestha, B. 2007a. ***Mountain Tsunamis.*** Our Planet Magazine, Climate Change and the Cryosphere issue. UNEP, Nairobi, 20-21.

Shrestha, B. 2007b. *Geographic information for sustainable mountain development in the Hindu Kush Himalayan (HKH) Region.* MENRIS/ICIMOD, Kathmandu.

Shrestha, B. and B. Bajracharya. 2007. Regional Spatial Data Infrastructure (RSDI) for Sustainable Mountain Development in the Hindu Kush Himalayan (HKH) Region. MENRIS/ICIMOD, Kathmandu.

Stone, P.B. (editor) 1992. *The State of the World's Mountains: A Global Report.* Zed Books Ltd, London and New York.

Thompson, M. and M. Warburton 1985. Uncertainty on Himalayan Scale. *Mountain Research and Development.* 5(2): 115-35.

UNDP. 2006. *Human Development Report 2006: Beyond scarcity: power, poverty and the global water crisis*. United Nations Development Programme, New York.

UNGA. 2004. *Report of the Inter-Agency Meeting on Outer Space Activities on its Twenty-fourth Session, Committee on the Peaceful Uses of Outer Space (Geneva, 21-23 January 2004).* United Nations General Assembly, A/AC. 105/818.

UNGIWG. 2007. *Strategy for Developing and Implementing a United Nations Spatial Data Infrastructure in Support of Humanitarian Response Economic Development Environmental Protection Peace and Safety.* United Nations, www.ungiwg.org/docs/unsdi/UNSDI Strategy Implementation Paper.pdf (visited 23 November 2007). United Nations Geospatial Infrastructure Working Group.

UNU. 2005. A United Nations University Climate Change Initiative, Sustainable Land Management in Central Asia. (Mountain Notes). *Mountain Research and Development.* 25(4) 372-75.

Wechsler, S. 2007. Uncertainties Associated with Digital Elevation Models for Hydrologic Applications: a review. *Hydrology and Earth System Sciences Discussions* (www.hydrol-earth-syst-sci.net/11.148.2001/).

Zurick, D., J. Pacheco, B. Shrestha, and B. Bajracharya, 2005**.** *Atlas of the Himalaya.* ICIMOD, Kathmandu, pages 96,