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The Challenge of Applying Geographic Information Systems to Sustainable Mountain Development

In recent years, Geographic Information Systems (GIS) have increasingly been used in a wide array of application contexts for development cooperation in lowlands and mountain areas. When used for planning, implementation, and monitoring, GIS is a versatile and highly efficient tool, particularly in mountain areas characterized by great spatial diversity and inaccessibility. However, the establishment and application of GIS in mountain regions generally presents considerable technical challenges. Moreover, it is necessary to address specific institutional and organizational issues regarding implementation.

The origin of Geographic Information Systems

The first digital Geographic Information Systems (GIS) were developed in the 1970s, with subsequent commercial and development applications in Western countries in the 1980s. Since then, an ever increasing number of development projects have made use of GIS in various contexts and geographical settings, particularly in lowland areas. As a result, a growing number of important decisions relating to natural resource management and development are being made on the basis of the spatial information and analytical capabilities available with GIS.

GIS functions encompass data storage and retrieval, visualization options, spatial analysis, modeling, and scenario building. Different socioeconomic and biophysical data can be combined at various map scales within the same coordinate system, with the advantage that information retrieval and updates can be significantly accelerated in comparison with conventional methods. The main current applications in the context of development are GIS-based resource assessments, planning tasks, and monitoring systems, all ultimately aiming at informed decision making that integrates socioeconomic and biophysical factors.

Critical issues in the context of development

Because GIS is a "postindustrialized technology" developed for the needs of societies in Europe and North America, a

FIGURE 1 Adequate representation of sloping lands is a technical challenge in mountain GIS. Pronounced topography and great diversity of features within short distances—as are visible in this view of Adi Shanet, a mountain village in Eritrea—are heavily underrepresented on maps. (Photo by T. Kohler)

number of critical issues must be considered when implementing GIS activities in developing or transition countries.

Organizational level

The introduction of GIS in a particular agency has repeatedly been observed to alter power relations in governmental structures. It has frequently been observed in various countries that the GIS units of government agencies become prestigious and that this entails "unhealthy" intragovernmental competition between different departments.

Adequate funding and staffing over a reasonable period of time are major factors in successful implementation. On the one hand, maintenance and support is necessary for the rapidly changing hard- and software requirements resulting from the short lifespan of computer technologies. On the other hand, empowering of local technical staff is a prerequisite for the sustainability of GIS activities. This can be achieved only by providing transfer of know-how and by continued backstopping based on a long-term commitment.

Data availability and legal level

In addition to organizational matters, data availability, data exchange, and legal issues are of paramount importance in the overall exploitation of the potentials of GIS for sustainable development. Development projects frequently operate in areas where accurate, up-to-date data barely exist or are difficult to access. It is frequently reported that data sharing and exchange are impeded by power considerations and political motivation within state administrations and civil society organizations (CSOs). Furthermore, the fact that governmental rules and laws concerning data exchange were usually established before the "digital revolution" and that they, therefore, are not yet adapted to today's requirements can also be a source of problems.

Technical level and practical interaction

At a technical level, data exchange among stakeholders is often further hampered or even made impossible by barely agreed upon data formats and projection standards, leading to unexploited synergies and costly duplication of efforts.

The close link between technical knowledge and knowledge about specific topics and practical issues is a crucial factor in the successful application of GIS. In contrast to academic research, development programs can seldom meet the thematic and technical requirements of GIS-related activities with 1 staff member or even a single unit. Hence, it is no surprise that GIS components tend to develop their own dynamics and become detached from overall objectives. This is probably a key to understanding why even GIS that are perfectly designed in technical terms too often fail to meet expectations and why their benefits and impact remain small compared with their actual potential.

GIS in mountain regions

In contrast to lowland regions, there is often a lack of reliable and accurate bases of spatial information in mountain areas. This impedes decision-making processes and implementation of strategies and development programs. The great natural variability and the small spatial scale of mountain regions make setting up a GIS a technical challenge. At an organizational level, implementation and exploitation of GIS in these regions involves similar but generally more demanding institutional challenges than in lowland areas.

Technical issues

The challenge of space and scale: Mountain landscapes are characterized by small spatial units and generally great variability. Great spatial variation in altitude results in small-scale patterns of climate, soil, land cover, hydrology, and biodiversity. Limited accessibility and relative remoteness often lead to the development of totally different cultural, land use, and livelihood systems within a comparatively small area. As a result, most development-relevant aspects and corresponding variables are characterized by great spatial heterogeneity, requiring refined technical approaches and superior inputs of information, ultimately leading to greater efforts (and costs) in data collection and analysis than in lowland areas.

"In 1995 roughly 25 GTZ development projects (Deutsche Gesellschaft für Technische Zusammenarbeit) involved some form of GIS activity; by 1999 this number had more than quadrupled, to approximately 120." (German Technical Cooperation 2000)

"Data sharing may be especially problematic in environments which are not 'information-driven' and in which bureaucracy presents particular obstacles. Competitiveness and empire building prevent the free flow of data because common goals are not shared." (Dunn et al 1997)

FIGURE 2 A typical village in the Pamir Mountains of Tajikistan. Small-scale patterns of land use systems in mountain areas require high-resolution input data for GIS. (Photo by Jean Schneider, published in: *Breu T, Hurni H.* 2003. *The Tajik Pamirs. Challenges of Sustainable Development in an Isolated Mountain Region*. Berne, Switzerland: Centre for Development and Environment, University of Berne.)

This great spatial heterogeneity implies that questions regarding spatial scale and scaling deserve special attention in mountain regions (Figure 2). Whenever the scale of measurement or observation is different from the scale at which the process under investigation is active, scale issues should be examined with great care. The scope of the scale issue and aggregation effects related to decision making in mountainous regions is illustrated here by an example in Northern Laos (see Box 1).

Better reflection of the reality of areas and distances on sloping land constitutes a major technical challenge for GIS techniques in mountainous regions (see Figure 1). Because GIS can rely only on projected information, resulting in a planar representation, actual areas and distances in mountain areas are generally underestimated. A large surface with a very steep slope is reduced to a negligible area on a map, and infrastructure such as roads and transmission lines on steep slopes is heavily underrepresented. For example, density models (eg population, wildlife habitats, etc) tend to be exaggerated as a result, and distances that appear shorter than they are in reality can lead to erroneous calculations of mountain infrastructure costs.

Interpolation and extrapolation: Interpolation and extrapolation tasks relating to sloping lands constitute a second major technical challenge. Spatial complexity and orographic effects require careful selection of input data to represent the different facets of spatial diversity. Accurate spatial models must deal with great variation in aspects of terrain and adiabatic gradients (eg temperature and rainfall) and require not only dense input data but often local expert knowledge as well. Modeling of plant and animal community distribution and climate models are examples.

Interpreting satellite imagery: Aerial photographs and high-resolution satellite imagery data are often indispensable sources of information in barely accessible mountain areas. From a technical standpoint, however, these information sources pose 2 major challenges. On the one hand, georeferencing and orthorectifying of remote sensing data in mountain areas requires an accurate Digital Terrain Model (DTM) and an above-average number of reliable ground control points. On the other hand, interpretation of remote sensing data sources faces the challenge of frequently marginal features (eg minimal biomass) and technical difficulties resulting from slope and shadow effects.

Institutional considerations

Organizational issues in mountainous regions: In developing countries, less attention is generally paid by central governments to the development of mountain regions. Legal competence, executive power, and financial resources at the level of the local government in mountain areas are often very limited, and considerably less is invested in collection and analysis of (spatial) information that contributes to sound decision making. In addition, decision makers in mountain regions are hardly aware of the possible applications of GIS; hence, local demand for GIS in these regions remains low. Besides limited demand, the restricted resources and capacities of local administrations impede the establishment and wider application of GIS. So far, most GIS activities in mountain regions have been implemented by CSOs for particular areas and applications, restricting the versatility of the database for further use by local administrations.

Data for mountain GIS: Generally, spatial information in mountain regions in developing and transition countries is incomplete, inhomogeneous, and outdated. Often, the only exception is detailed spatial databases relating to economically viable natural resources (eg mining potential, hydropower) in specific areas of limited extent.

A major obstacle in the use of spatial data is difficulty of access. Geographic information, whether in conventional (eg maps, aerial photographs) or digital form (GIS and remote sensing data), is usually kept at governmental facilities at the national level and can often be accessed only after lengthy procedures, usually due to national security considerations. In many mountain regions, GIS data are almost exclusively collected and used by local projects. However, coordination among the different organizations working in mountain regions is rather poor; competition can even be observed in some cases. This repeatedly leads to scattered databases with different formats and reference systems, which are of little use for aggregation on a smaller scale.

GIS capacities in mountains: GIS capacity has not yet been developed in most of the world's mountain regions, whether in public administration or in the private service sector, including CSOs. To strengthen locally supported development efforts, interested mountain regions with external support need to focus on human resources development and knowledge transfer as the first priority. Because computer technology is generally less widespread in mountain regions, greater initial training efforts will probably be needed to pave the ground for more specific needs in handling GIS software. No less important than well-trained GIS staff are favorable working conditions to reduce frequent high turnover of technicians with

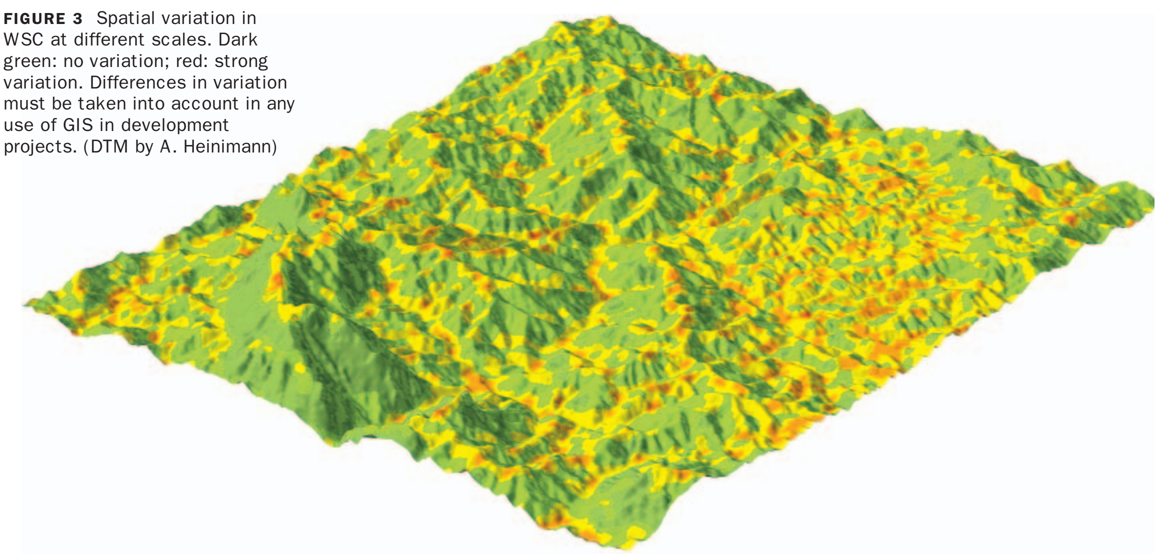
Scale challenges in mountain GIS: a case in Laos

The heterogeneity and compartmentalization of mountain regions imply that questions regarding scale and scaling are of great importance. In these highly diverse environments, the results of each spatial analysis exercise depend heavily on the scale at which it is conducted. To illustrate scale effects, a watershed classification (WSC) model in Laos was processed at different scales.

The WSC model, designed as a planning tool for watershed management in the Lower Mekong Basin by the Mekong River Commission (MRC), gives an indication of the sensitivity of watersheds regarding natural resources degradation. On the basis of slope, elevation, and landform parameters, 5 watershed classes were delineated. Watershed classes 1 and 2 represent the most sensitive (or critical) and classes 3–5 the least sensitive (or noncritical) areas in terms of potential soil erosion risk.

For a test area of approximately 30,000 km^2 in Northern Laos, Water Classification Schemes on the basis of DTMs with different resolutions were derived and resulting scale effects compared. Starting from the original Digital Terrain Model (DTM) with a resolution of 50 m (based on a 1:50,000 topographic map series), a set of terrain models with decreasing resolutions, representing artificial scales, was prepared. When the behavior of the critical and noncritical areas is examined across the scale continuum, the tremendous variation in the relative proportions, depending on the scale of analysis, becomes obvious (Figure 4).

FIGURE 3 Spatial variation in WSC at different scales. Dark green: no variation; red: strong variation. Differences in variation must be taken into account in any use of GIS in development projects. (DTM by A. Heinimann)



their almost traditionally low professional reputation in developing countries. To increase the sustainability of efforts to build up GIS capacity, mechanisms that enable revenue generation, leading to self-financing of equipment and expendables, should be envisaged. Experience with successful GIS activities shows that this process for developing capacities must be supported beyond an initial stage and that continued external technical support and advice are needed for a relatively long period.

Recommendations

Overall, it can be concluded that the main challenges of GIS in mountain development, as in development in general, are of a nontechnical nature. In mountain regions, however, the application of GIS presents special problems and requires specific skills to provide meaningful outputs.

Technical

Mountain areas are challenging environments for GIS application, owing to their

During the up-scaling and aggregation process, adjacent smaller units are agglomerated. As a result, the smoothing process suppresses variance and uniqueness over the entire study area. However, this effect starts only at a critical threshold between resolutions of 75 and 100 m (Figure 4), thereby indicating that scale effects are bound by discrete changes and critical scales.

When analyzing the location of changes occurring in WSC classes as a result of varying scales, it becomes obvious that these do not appear homogeneously over the whole area. Figure 3 indicates regions of high- and low-scale dependency and clearly shows that when moving up in the scale continuum, the smoothing process leads to great losses, mainly in microrelief and along landscape features such as valleys and ridges.

This example clearly shows the significant effects of scale and aggregation on results derived from spatial data in mountain areas. It also highlights the direct relevance of scale effects for planning and decision making—in this case in the context of formulating land use and forest policies in the Mekong countries.

Source: *Heinimann A, Cassel-Gintz M, Wiesmann U.* 2003. *The Scale Challenge in Policy-Oriented GIS Applications in Mountain Environments*. NCCR North–South Dialogue 2. Available from NCCR North–South Management Centre (www.nccr-north-south.unibe.ch).

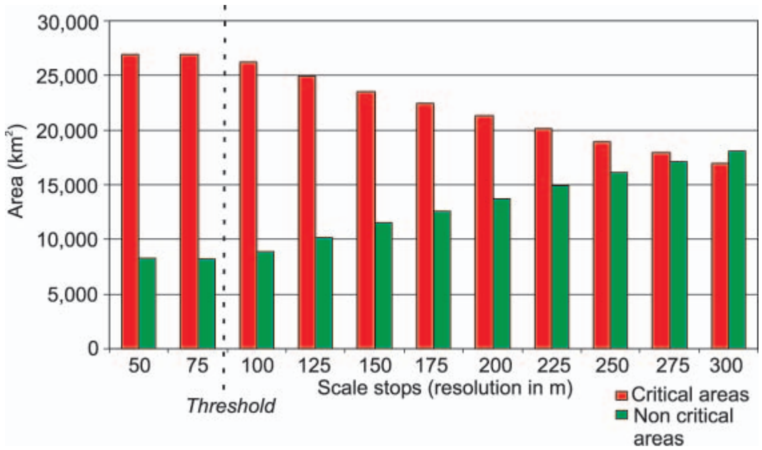


FIGURE 4 Effect of data aggregation on share of critical and noncritical areas. (Source: Heinimann et al 2003)

FIGURE 5 The key to successful GIS activities in development is continued technical and topical backstopping, preferably through South–South cooperation. (Photo by A. Heinimann)

pronounced topography and their great diversity within short distances. Comprehensive GIS capacity building should include the following fields:

- Technical skills.
- Interpretation of outputs.
- Basic understanding of mountain development issues.
- Communication of results to users and decision makers.

This is the only way to enable trainees and future GIS experts to provide useful and specifically tailored information and to create awareness of the usefulness of GIS in mountain development.

Institutional

Isolated establishment of GIS and spatial databases for specific mountain areas by development programs and projects or regional authorities seems to be the order of the day in many mountain regions of the world. These initiatives often use different hard- and software tools and different processing methods, even when operating in the same geographical areas. This makes exchange of data and data integration extremely time consuming or even impossible. Hence, there is a need for a national authority, such as a mapping agency, to set technical standards and provide basic reference data (eg DTMs, political boundaries). Programs operating on a regional or local basis should be made to abide by the standards and formats set by authorities. Likewise, they should seek to integrate relevant data into a national or regional GIS in a bid to establish a database that survives the lifecycles of individual projects.

Even if such a national agency or authority exists, it is often difficult to get data from it. Knowledge is power, and it is as easily monopolized as power. Regarding data on mountain areas, this data monopoly effect is often compounded by national security considerations because mountains are often border areas or army strongholds—a phenomenon by no means limited to developing countries. Issues pertaining to monopolies, security considerations, and data ownership and sharing should be carefully looked into before embarking on GIS activities. Luckily, satellite technology provides a means to undermine and circumvent such monopolies today, although still at a considerable cost.

Since the integration of GIS in development projects began in the late 1980s, it has been maintained that the dominance of external investment will gradually decrease. Unfortunately, this has happened only in very few cases; in fact, the developing world is as dependent on international expertise as ever in the field of information technology, including GIS. Hence, serious efforts should be made to engage in long-term human resource development and capacity building with respect to technical and topical issues relating to GIS. In addition, the potential for South–South collaboration in the field of GIS is far from being exploited. This is partly due to the fact that the overwhelming majority of vendors of commercial GIS software are located in the North and that GIS projects are still largely initiated by foreign advisors who have experience with specific systems. Promotion of a South–South link should emphasize strengthening of specific national and regional GIS user groups and unions (Figure 5).

Promotion of a regionalized network of competent local private firms would support users in public services and development programs with expertise and consulting services. Development agencies can help strengthen such firms by integrating them in their activities at an early stage. This integration of the private sector, accompanied by a mid- to long-term commitment to support respective local educational facilities, would be a crucial advance along the road to local empowerment.

Last but not least, a major key to success will be to prevent "brain drain" from marginal mountain areas to governmental and development agencies by enhancing the general working conditions of trained GIS professionals.

Political

In many countries, mountain areas are politically marginalized, and local needs are rarely considered in mountain development agendas. If used in such political contexts, GIS is likely to accentuate the policies of exploitation of mountain resources and penetration of fragile mountain areas keyed to the needs of lowland areas and currently prevailing in many mountain areas of the world. However, GIS can be a powerful tool for sustainable mountain development if conditions at the national political level:

- Allow for inclusion of local agendas in development.
- Are based on mitigating processes that include, for example, lowland and mountain stakeholders.
- Put negotiated outcomes and policy dialogue high on the political agenda.

Even if local mountain agendas and local knowledge are included in decision-making processes, it should be noted that better information does not necessarily lead to better decisions. Decisions are often not the result of spatial information alone but are guided by factors such as politics, power relations, and personal benefit. Christiansen (1998) argues that "the less rational the management culture, the less useful an information system will be." Nevertheless, experience has shown that relevant spatial data, keyed to users' needs, and well presented and explained, can strengthen rational decision making at all levels, including benefits for mountain areas and their populations.

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