The use of Geographical Information Systems for research and development in the Andean Ecoregion[1]

Robert J. Hijmans and Percy Zorogastúa
International Potato Center, Lima, Peru

Introduction

Mountain agro-ecosystems are famous for their high spatial complexity and diversity. This complexity and diversity make it more difficult to describe, understand and help improve patterns of land use in mountain areas. A Geographic Information System (GIS) is an important tool that can be used to come to grips with the spatial diversity of mountain environments.

GIS are computer-based tools that are used to store, display, and analyze spatial data. With a GIS environmental data can be made readily accessible, and it can be easily combined and modified. GIS can improve environmental decision-making, by making it better informed and more explicitly reasoned (Eastman *et al*., 1995). GIS is a young technology that has been applied in many subject areas, especially in the environmental sciences and management. See Denisov *et al*. (1997) for a collection of case studies.

This paper briefly reviews the various uses of GIS; it then discusses some problems and pitfalls; followed by three examples of its use in the Andean ecoregion; and finally discusses the role that CONDESAN might play in stimulating a rational and effective use of GIS.

What can GIS do for you?

Four important types of GIS use can be distinguished:

1) inventory and map making
2) monitoring and evaluation of resource use
3) spatial analysis
4) decision making

Inventory and map making

GIS can be used to bring together a number of spatial databases, often derived from paper maps. These databases typically include altitude, climate, soil, land use, infrastructure

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and administrative boundaries, among others. By storing them in a common digital format, they can be retrieved and combined at will to produce new maps. This is probably the most common use of GIS. It is especially relevant if many maps are produced for the same area, at a comparable scale. In that case data layers of, for example, roads, rivers and administrative boundaries can be used several times, and there are many thematic features that can be combined. It allows zooming in to specific smaller areas and putting then on separate maps. With a GIS, maps can be printed at a scale desired and with an optimal amount of information, so that it can be used to discuss interventions with stakeholders (from politicians to farmers), or for inclusion in reports and other publications.

Sometimes GIS is used to digitize a map and then print a few copies of it. This is very expensive way of reproducing maps (think of hardware, software, training and salary). In those cases it could be much more efficient to make photocopies.

Monitoring and evaluation of resource use

Los GIS se pueden utilizar para el establecimiento de una base de datos del estado de los recursos naturales en un determinado momento, a partir del cual se puede ir realizando un seguimiento de las actividades de intervención en un lugar. Así se puede seguir los cambios de uso de la tierra en determinada región. Having a map in a GIS also allows for relative easy updating of features that change over time. Data derived with remote sensing (satellites) looms large in resource monitoring projects.

En las evaluaciones del impacto ambiental el SIG ayuda a analizar escenarios en donde se podría realizar preguntas como "Qué sucedería si?". Por ejemplo si aumenta el area irrigada, o si se dispone de un mayor volumen de agua sube la napa freática? Cuáles serian los efectos del suministro de una mayor cantidad de agua a los campos, aumentaría la cantidad de sales? Cuáles serían las áreas más afectadas? Cuanto es el beneficio económico a largo plazo de la construcción de terrazas?

Spatial analysis

GIS can be used to increase our understanding of the world. Many important environmental issues are difficult to understand because of spatial variability. The classic example is that of John Snow who mapped the incidence of cholera in 19^{th} century London. When he also mapped the locations of street pumps, it became clear that cholera transmission is related to infected water. This was not previously understood

In a similar vein, scientist in the Andean ecoregion search for spatial relationships. Ongoing research includes studies between poverty and resource use, and the effect on soil degradation. Another example is the study of the determinants of the presence of high levels of biodiversity, finding out whether these are related to climate, isolation, poverty or other factors. Spatial analysis is mainly carried out by research organizations and universities. In many cases, its results should be of importance to policy makers.

Decision making

GIS can be used for planning purposes. It can help in the decision making process to allocate investments in soil conservation, irrigation, or other infrastructure. It can be used for an optimal allocation of biological reserves. También se puede utilizar el SIG para evaluar situaciones de riesgo en áreas frágiles, susceptibles a deslizamientos y/o avalanchas. Se lo puede utilizar en la optimización en el trazo de nuevas rutas o vias, ó lineas de distribución de energía/agua, la localización óptima de centros de acopio, centros de venta , centros asistenciales, centros de procesamiento de productos.
This type of GIS use is especially important for government agencies and NGOs.

When (not) to use it

GIS use should only be considered as a tool to improve and extend existing research and development, and not as a separate area of work, or as a goal in itself. Having said that, it should be realized that there is need for trained staff, up-to-date soft and hardware, and a long-term commitment for database creation and maintenance. The institutional setting is crucial, and more important then the hard- and software used. GIS can only flourish in an atmosphere of for long-term commitment and a strong interaction between the GIS technicians and their colleagues.

GIS is often seen as expensive, complex, inaccessible and alienating to decision-makers (Eastman et al., 1995). GIS can empower people, making data more equitable accessible, and decision taking more transparent. But GIS can also create distance between the class of GIS analysts and those that would need to use their results. This then impedes the use of GIS analyses, and may hinder focusing on the more important questions. For a GIS to be successful in an organization, decision-makers and stakeholders should dictate the development of GIS and not vice versa.

Data and software

Successful GIS use needs relevant research questions, technical skills and a lot of data. When assuming that the skills and research questions are in ample supply, next to nothing can be done without a considerable amount of databases. Therefore, starting a GIS, is starting a data crisis. This is often overlooked in research proposals.

Typical problems encountered when assembling databases include a lack of data; difficult access to data because of institutional formalities, copyright problems, etc.; data may have to be digitized, this can be rather tedious for time series of daily weather data! Original paper maps are sometimes not available while the copies that are available are geometrically distorted.

A change in mentality about the collection of data is needed. Many national entities already collect data (like weather and census data) but access is limited and could be improved. While doing fieldwork people should take a GPS to precisely determine the locations of their observations.

Mountain issues

Mountain environments are areas of high relief and this three-dimensionality of mountain areas needs to be taken into consideration in GIS applications (Heywood *et al.*, 1994). Not only because of the effect of altitude on climate, but also because of the effect of differences in aspect and slope. In the case of frost damage, for example, aspect is a determinant of the time of the day when a slope can receive solar radiation. Due to slope, cold air drains downwards during the night and can lead to a climate inversion with colder areas in the valley bottoms than on the higher slopes. Soil erosion and water flows are obviously strongly influenced by slope too.

GIS, like maps, generally deals with the world as if it where flat. However, GIS can take three dimensions into account by making two dimensional models of aspect, slope and height. Scale is another important issue in mountain areas. The Andean landscape often consists of scattered small plots and other land units. This diversity may well disappear when data is aggregated too much. But trying to capture every single field may be practically impossible, so a balance needs to be struck.

A reasonable balance need to be struck to decide when GIS can be used, and up to what point in a planning process. The results should not be taken as the one-and-only-truth, and be interpreted with care. There is a need for a more statistical approach to maps and intervention plans. Where possible these should be supplied together with confidence intervals and other indicators of uncertainty.

Case Studies

Cajamarca: land degradation intervention plans for La Encañada

Many GIS databases have been developed for the CONDESAN bench mark site in Cajamarca (these will be published in Hijmans *et al*., 1998). These databases are now being used in various research and development projects. We present a simplified example of how GIS is used to determine areas for intervention of soil conservation measures in the La Encañda catchment.

A land use map was made on basis of air photos and field work (Figura 1a). A GIS database with 50 meter contours of La Encanada was developed by digitizing 1:25,000 scale maps. The contours were interpolated on a 10 by 10 meter grid that was subsequently used to create a digital slope map. Slopes were then put into three classes (Figura 1b):

I	0 - 10°	(0 - 19.4%)	- Suitable for crops
II	11-17°	(19.5 - 30.5%)	- Less suitable for crops
III	> 17°	(> 30.5 %)	- Not suitable for crops

An overlay of this slope-class map with the land use map was made. The resulting "Land use conflict map" (Figura 1c) has three categories: uso adecuado en 4430 ha (68 %), uso inadecuado en1134 ha (18 %) y uso muy inadecuado en 908 ha. (14 %). Despues so uso otra variable, profundidad de los suelos, para priorizar areas de intervencion, a fin de escoger las áreas que tengan mas posibilidades de mayor impacto productivo.

La intersección de las coberturas de conflictos de uso de la tierra y la profundidad de los suelos resultó en 4428 ha de tierras adecuadamente utilizadas en diferentes profundidades, 349 ha de uso inadecuado en profundidades mayores a 60 cm, 786 ha de uso inadecuado con profundidades menores a 60 cm, 262 ha de uso muy inadecuado con profundidades mayores a 60 cm y 646 ha de uso muy inadecuado en profundidades menores a 60 cm (Figura 1d).

The following interventions are suggested:

Use	Soil depth	intervention
Inadequate	> 60 cm	terraces, infiltration ditches, etc.
Inadequate	< 60 cm	use for permanent crops (pasture)
Very inadequate	> 60 cm	exotic tree species (fast growing)
Very inadequate	< 60 cm	native tree species

Use
Inadequate use

Altiplano: frost zonfication

Much of the rural population of the Altiplano consists of poor, semi-subsistence farmers. In most agricultural areas of the Altiplano, the cold and dry conditions allow for the production of a relatively small number of crops that are drought and cold tolerant, such as bitter potato and quinoa. Variability of rainfall and frost risk is high. Especially in “El Niño” years disastrous droughts may occur. Various technologies have been developed to mitigate the frost and drought problem (e.g., raised beds, rustic greenhouses, frost tolerance in potatoes). GIS has been used to make climate maps that allow the more rational selection of test sites, targeting technology and assessing their impact.

Climate data was taken from a large database with data of 54 weather stations. For most of these there is data for 30 years of more. With this data, climate surfaces were created , using altitude as a co-variate, at 30-arc seconds resolution (approximately 1 km^2). As an example, maps that indicate frost risk for the Altiplano are presented (Figure 2).

The data was used, together with a crop growth simulation model, for an ex-ante impact assessment of the potential benefit of frost tolerant potato cultivars, with a tolerance of -3°C instead of -1°C. It was estimated that potato yields in the Altiplano could go up, on the average, with 17%.

Diversity: Crop distribution and genebank data

GIS databases of crop distribution (Figure 4) and of the location sites where germplasm was collected are under development. Guidelines for the tedious cleaning of germplasm databases have been developed (Hijmans *et al.*, 1999). These databases help in analyzing spatial biases in germplasm collections. For example, it was shown that there is a strong road bias in the wild potato collection from Bolivia (Figure 3; Hijmans *et al.*, 1999). It also helps in selecting areas where future collection should take place, and of the areas that are most suitable for in-situ conservation. Finally, these data can be used to investigate the relation between certain crop characteristics, such as resistance, and climate or other spatial variables. This can generate useful knowledge for breeding programs. Currently the data from several Andean root and tuber crops genebanks from Andean countries is being worked on, Valladolid *et al.* (1996) reports some first results.

<u>What should CONDESAN do?</u>

Promote access to data

Because of the information technology revolution we are witnesses of, more data and mapping tools will become available and at a lower cost. Yet whether databases are created in house or acquired from outside, there are always costs associated with them. A lot of data sets are generated these days, but in many cases it is unclear if and when the databases will become available. There is a need to educate donors who finance these projects. They should insist on publication of data sets. CONDESAN could play a role in setting the example, by making funds available for data-set documentation and distribution. INFOANDINA could play a key role in dissemination of GIS data on the Andean ecoregion.

Develop adequate methods

CONDESAN can play a role in the design, adapt, test, and spread methods for GIS use to steer development interventions. Special emphasis should be placed on technology that is "just good enough", using a "minimum data set" approach. The rationale is that many methods developed in other countries can not be readily applied because of the cost, the lower availability of data, and the differences in ecology. One has to dare to be as rough as possible to be able to deliver a product within a reasonable time frame. Research that explicitly deals with these questions of scale and detail is underway in La Encañada.

Bring people together

Thirdly, CONDESAN can play an important role in organizing meetings, electronic conferences, training and the publication of documents about GIS use for Andean natural resources management.

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